# SOIL VAPOR EXTRACTION/PNEUMATIC FRACTURING PILOT TEST REPORT

# AT THE GRANVILLE SOLVENTS SITE GRANVILLE, OHIO



**Submitted to**

**The United States Environmental Protection Agency**
**Emergency Response Branch**
**Region V**
**Chicago, Illinois 60673**

**August 22, 2000**

**Developed for the**

**Granville Solvents PRP Group**
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August 22, 2000

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**Subject: Granville Solvents Site Removal Action**
**Soil Vapor Extraction/Pneumatic Fracturing Pilot Test Report**

Dear Mr. Adler:

Attached to this correspondence for your review is the Soil Vapor Extraction/Pneumatic Fracturing Pilot Test Report for the Granville Solvents Site.

If you have questions or comments regarding this submittal, please contact Mr. Michael Raimonde or me at (614) 890-5501.

Respectfully,

**METCALF & EDDY OF OHIO, INC.**

Michael Raimonde for

Gerald R. Myers
Vice President/Project Coordinator

cc: B. Pfefferle, Chairman - GSS PRP Group Technical Committee
Gerry Myers, M&E, Site Coordinator
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# Executive Summary

## EXECUTIVE SUMMARY

Granville Solvents, Inc. is a former solvent blending and recycling facility located on a 1.5-acre parcel in the Village of Granville, Ohio. The parcel is located within the hydraulic influence of the Village of Granville well field that is located 700 feet to the west of the facility. Groundwater and soil beneath the site contain volatile organic compounds. The Administrative Order on Consent (1994), between the U.S. EPA and a group of potentially responsible parties at the Granville Solvents Site, requires the completion of certain Removal Actions. These include, among others, a requirement to install a groundwater pump and treat system and a requirement for the treatment of soils to reduce levels of contaminants so that no groundwater beneath the soils will become contaminated above No Further Action Levels.

A groundwater pump and treat system has been in operation since 1994. An Engineering Evaluation/Cost Analysis (EE/CA) issued in August 1999 addressed soil treatment requirements for volatile organic compounds based on data collected regarding the contaminants in soil and groundwater. It is apparent from the analysis that it will be necessary to treat soils to certain criteria to assure that groundwater beneath the soils will not become contaminated above the No Further Action Levels. These criteria, or soil treatment goals, were established using numerical modeling and risk assessment methods. Only two compounds detected in the soil, trichloroethene (TCE, 6.67 mg/Kg) and perchloroethene (PCE, 5.53mg/Kg), exceed soil treatment goals.

Of the alternatives to address soil considered in the EE/CA, soil vapor extraction was selected. Because of the fine-grained nature of the soil encountered during several investigations in the first 20 feet below the land surface, pneumatic fracturing was proposed to enhance the air permeability of the soil. A pilot test was conducted to evaluate the site-specific performance of soil vapor extraction and the effect of pneumatic fracturing. Thirteen vacuum monitoring wells and two pneumatically fractured vapor extraction wells were installed. The lithology in the pilot test area consists of 7 to 12 feet of clay-rich material (clay unit) underlain by sand and gravel (sand unit). The depth of the groundwater table is approximately 20 feet in the area of the pilot test.

The pilot test consisted of soil vapor extraction, pneumatic fracturing, and pressurized air injection tests in the clay unit and soil vapor extraction tests in the underlying sand unit. Short-term soil vapor extraction testing was conducted in well VP-10 both before and after fracturing. VP-10 is located ten feet away from the fracturing site. Results indicated an increase in permeability of 19 percent and an increase in the airflow rate of 26 percent following pneumatic fracturing. The tests were conducted using a vacuum of 10 and 12 inches of mercury (136 to 163 inches of water). The mass removal rate decreased after fracturing by over 50 percent. Testing was complicated by rainfall events. The radius of influence remained similar in all tests and averaged 18 feet.

A long-term test of two pneumatically fractured soil vapor extraction wells (Wells # PF-1 and PF-2) indicated increased airflow over time under the influence of 10 inches of mercury (136 inches of water). Rainfall events resulted in short-term decreases in airflow which were followed by progressive increases. Rainfall also resulted in water collecting in well sumps requiring periodic removal. The radius of vacuum influence remained at approximately 18 feet. The removal of contaminant mass progressively increased during the course of the pilot test.

Air injection tests were conducted on the pneumatically fractured wells. Air injection rates were equivalent to the air extraction rates achieved in the soil vapor extraction tests. This flow rate was obtained using 48 percent less pressure (70 inches of water versus 136 inches of water). Water did not collect in the well sumps during the course of the air injection test.

Tests in the sand and gravel beneath the clay resulted in airflow rates of 120 standard cubic feet per minute (scfm). While two sand-unit wells were operated within this unit, the radius of influence covered the entire area impacted above soil treatment goals, although there appears to be restricted flow beneath the building. The restricted flow was likely caused by greater thickness of the clay-unit and lesser thickness of the sand unit beneath the building. Vacuum pressure during the test averaged 12 inches of water. Mass removal rates were gradually declining during the course of the testing in the sand unit.

The aggregate concentration of volatile organic compounds measured using a photoionization detector (PID) during the long-term clay-unit test steadily increased. At the end of the test, the concentration was 25 ppmV while at a flow rate of 70 scfm. This represents a removal rate of approximately 0.9 pounds per day. After operating the sand-unit test for 30 days, the measurement using a PID was 70ppmV with a flow rate of 125 scfm. This represents a removal rate of approximately 4.3 pounds per day with a declining trend.

*Conclusions drawn from the pilot test are:*

- The clay unit beneath the site is seven to 12 feet thick where measured in the test area.
- Soil vapor extraction in the clay unit, without pneumatic fracturing, is feasible.
- Pneumatic fracturing resulted in a modest increase in airflow rates over those obtained under natural conditions in the clay unit.
- The test did not provide evidence that pneumatic fracturing will increase the radius of effective influence of the soil vapor extraction system in the clay unit.
- The test did not provide evidence that pneumatic fracturing will quantitatively increase the rate of mass removal from the clay-unit.
- An unsaturated sand unit is present beneath the impacted area of the site and beneath the clay unit.
- Soil vapor extraction is feasible in the sand unit.

# 1

# Section One

# 1. INTRODUCTION

## 1.1 HISTORY

The Administrative Order on Consent (AOC, 1994) between the U.S. EPA and a group of Potentially Responsible Parties (PRPs) at the Granville Solvents Site (GSS PRP Group) requires the completion of certain Removal Actions at the Granville Solvents Site (Site). These Removal Actions include the installation of a pump and treat system to halt migration of groundwater contamination toward the Village of Granville municipal wellfield; reinstatement of the capacity of the Village of Granville production well (PW-1); and treatment of soils to levels so that no groundwater beneath the soils will become contaminated above the groundwater No Further Action Levels. The GSS PRP Group installed, and is operating, a groundwater pump and treat system and has provided a new production well for the Village of Granville.

The *Engineering Evaluation/Cost Analysis* (EE/CA, 1999) addressed the soil treatment requirements of the AOC. Data have been collected in previous investigations to characterize soil and groundwater conditions (M&E, 1995a-d and 1996a-f). These data have been evaluated, and the extent and distribution of contaminants in the soil and groundwater have been defined. The results of these investigations indicate that chlorinated and non-chlorinated volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) have been detected at the Site. The compounds in the soil are primarily located in the vicinity of the warehouse building.

A detailed analysis of the Site conditions was presented in the EE/CA (1999). This analysis determined that to comply with the requirements of the AOC and the Action Memorandum (U.S. EPA, 2000), it will be necessary to treat soil to the treatment criteria listed in Table 1. Two compounds, trichloroethylene (TCE) and tetrachloroethylene (PCE), have been detected in site soils in excess of the soil treatment goals. The soil treatment goals for these compounds are 5.53 mg/kg for PCE and 6.67 mg/kg for TCE. By treating site soils to these goals, the requirements of the AOC will have been met.

## TABLE 1

## SOIL TREATMENT GOALS

| Chemicals of Concern | Maximum Concentration Detected in Soil (mg/kg) | Risk-Based Soil Treatment Goal* (mg/kg) |
|---|---|---|
| 1,1,1-trichloroethane | 1.7 | 147.81 |
| 1,1,2-trichloroethane | 0.012 | 4 |
| 1,1-dichloroethane | 0.011 | 59.22 |
| 1,1-dichloroethene | 0.007 | 0.0274 |
| cis-1,2-dichloroethene | 4.6 | 48.85 |
| trans-1,2-dichloroethene | 0.021 | 94.74 |
| 2-butanone | 0.014 | 360 |
| Acetone | 0.084 | 139 |
| Benzene | 0.014 | 3 |
| Carbon disulfide | 0.7 | 4 |
| Chlorobenzene | 0.027 | 66 |
| Chloroform | 0.002 | 62 |
| Ethylbenzene | 3.6 | 320.59 |
| Methylene chloride | 0.002 | 1.6 |
| Tetrachloroethene | 18 | 5.53 |
| Toluene | 0.34 | 725.20 |
| Trichloroethene | 11 | 6.67 |
| Vinyl chloride | 0.03 | 0.44 |
| Xylenes (total) | 44 | 907.00 |

* Risk-based soil treatment goals established in EE/CA (1999).

Five alternatives were identified in the EE/CA (1999) as potential Removal Actions that would reduce the concentrations of PCE and TCE in the soil to below soil treatment goals. Each alternative was evaluated based on the NCP criteria and the Superfund Accelerated Cleanup Model (SACM) guidance. The properties of the chemicals of concern are similar, allowing all of the chemicals of concern to be addressed using one technology. The results of this evaluation indicated that soil vapor extraction (SVE) with pneumatic fracturing, as necessary, would be an appropriate and cost effective action.

The U.S. EPA approved an Action Memorandum dated March 8, 2000, which was received by the Granville Solvents PRP Group on March 15, 2000, that recommended soil vapor extraction and pneumatic fracturing as an enhancement.

Although pneumatic fracturing-enhanced soil vapor extraction has been used successfully at many sites throughout the country, its site-specific performance must be evaluated to verify that the site conditions are compatible with the technology. Pursuant to this site-specific evaluation, a *Pneumatic Fracturing/Soil Vapor Extraction Pilot Test Work Plan* (Work Plan) (M&E, 2000a) was submitted on April 14, 2000 and approved by the U.S. EPA on April 21, 2000.

The pneumatic fracturing/soil vapor extraction pilot test commenced on April 27, 2000. The test was designed to include several specific activities. These include the installation of vacuum extraction and monitoring wells, SVE testing prior to fracturing soils, pneumatic fracturing of certain wells, and both short- and long-term SVE tests following fracturing. Metcalf & Eddy (M&E) and subcontractor ARS Technologies (ARS) conducted soil vapor extraction testing, pneumatic fracturing, and post-fracturing soil vapor extraction testing during the first week of May 2000 following the testing methods prescribed in the Work Plan. M&E conducted additional testing to collect supplemental performance data.

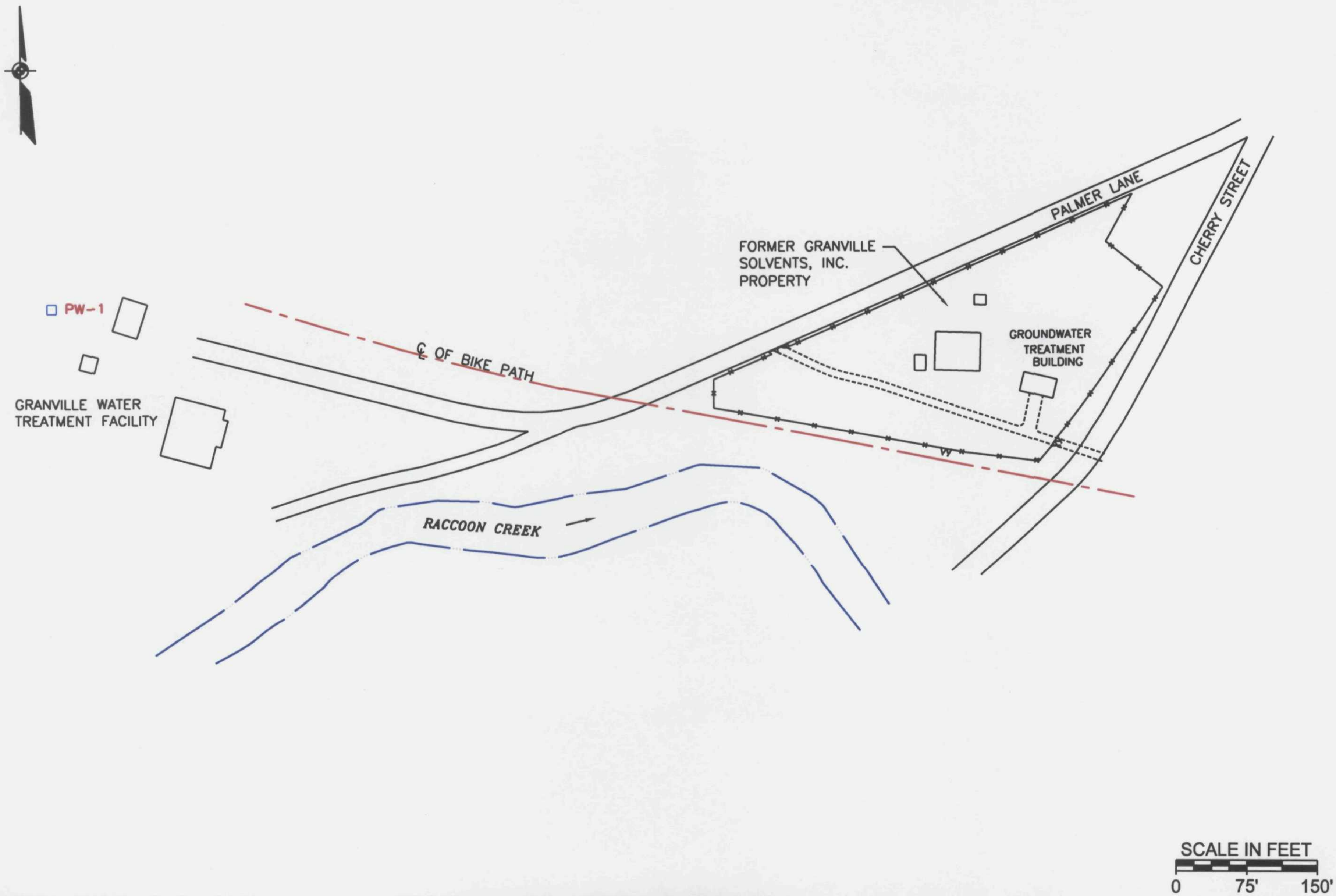
During the pilot test, several modifications were made to accommodate unexpected field conditions. An addendum to the Work Plan (M&E, 2000b) describing additional work to be conducted to address the field conditions, was submitted to the U.S. EPA on May 25, 2000. The addendum reported the preliminary results of pneumatic fracturing and clay-unit testing and defined this additional work including the drilling of two additional soil borings to evaluate the thickness of the clay-rich surface material and underlying sand unit immediately south of the warehouse building. The addendum also included the description of additional testing to be conducted to evaluate soil vapor extraction in the sand unit. M&E executed the additional work described in the addendum in June 2000.

This pilot test report contains the results of all pilot test activities. Following in Section 1.2 is a brief description of the site conditions, a description of the test objectives (Section 1.3) and an overview of the technology (Section 1.4). Details regarding the pilot test vacuum monitoring and extraction wells are provided in Section 2. Section 3 includes a description of the clay-unit test and its results. A description of the sand unit test and its results are provided in Section 4. The summary and conclusions are provided in Section 5. M&E's subcontractor, ARS Technologies, conducted portions of the work and provided a report that is included as Appendix A and summarized in the appropriate sections of this report.

## 1.2 SITE CONDITIONS

The Site is the location of an inactive waste solvent blending and recycling operation at 300 Palmer Lane in Granville, Licking County, Ohio (Figure 1). It is located near the southern corporate limit of the Village of Granville, but within the Village boundaries, approximately one-third of a mile southwest of downtown Granville. The Site is on a 1.5-acre triangular-shaped parcel located adjacent to a residential area, with some commercial and light-industrial business nearby. Palmer Lane is along the northwest site boundary. A former railroad track, now a bike and walking path, is the southern border of the Site with the Cherry Street overpass bordering the Site on the east. Raccoon Creek is located approximately 100 feet south of the walking and bike path. The Village of Granville municipal well PW-1, which has been removed from service, is located 700 feet west of the Site. The Site is zoned for commercial use.

The Site is situated on alluvial terrace deposits at the northern edge of Raccoon Creek Valley. It is directly underlain by clay-, silt- and sand-rich sediments deposited on the Raccoon Creek floodplain. Below the surface soil material is a highly permeable sand and gravel outwash. The finer-grained surface materials may retard but do not form a hydraulic barrier to the infiltration of precipitation from the surface. A typical vertical lithologic section expected beneath the site, based on lithologic logs from drilling, is a low permeability unit of interbedded fine-grained sand, silt, and clay lenses from the ground surface down to a depth ranging from 6 feet bgs to 20 feet bgs.

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GRANVILLE SOLVENTS SITE

# SITE LOCATION MAP

GRANVILLE, OHIO

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The thickness of this low-permeability unit in the area of the pilot test and the area under which soil treatment criteria are exceeded is approximately 10 feet. Extending beneath the water table, the aquifer consists chiefly of fine- to coarse-grained sand and silt, interbedded with gravel lenses of various thicknesses.

All of the chemicals of concern, (COCs) are volatile organic compounds (VOCs) which possess similar physical properties, allowing for all of the chemicals to be addressed using one technology. Soil vapor extraction is a presumptive remedy for VOCs. The relatively low permeability of the clay, however, provides limitations to this technology. One means of improving the permeability is by fracturing these fine-grained materials.

## 1.3 OBJECTIVES

The objectives of the pneumatic fracturing-enhanced soil vapor extraction pilot test were to: (1) evaluate the influence of pneumatic fracturing on the soil formation and (2) evaluate its potential to enhance remedial efforts in contaminated areas prior to and after fracturing activities. The following parameters were measured in accordance with the methods described in the Work Plan:

- Natural or pre-fracture baseline bulk air permeability and mass removal rates;
- Pressure requirements for fracture initiation and maintenance;
- Extent of fracture propagation and orientation; and
- Post-fracture bulk air permeability and contaminant mass removal rates.

The objectives of the soil vapor extraction testing conducted on the sand unit were to: (1) verify the presence of the sand unit south of the warehouse building beneath the area containing chemicals of concern in excess of the treatment standards, (2) evaluate the extraction flow rate and radius of influence of vacuum applied to the sand unit, and (3) evaluate the concentration of

VOCs in the extracted soil gas. To meet these objectives, the following activities were conducted:

- Drilling and detailed lithologic logging of two additional borings and the installation of vacuum monitoring wells south of the warehouse building;
- Installation and operation of a second SVE unit on a previously installed sand unit well VP-8; and
- Bulk air permeability testing of the sand unit and mass removal rate monitoring of the off-gas from the second SVE unit.

## 1.4 TECHNOLOGY OVERVIEW

With SVE, air flow is induced through contaminated soil by applying a vacuum to vapor extraction vents and creating a pressure gradient in the vadose zone of the targeted soil. As the soil vapor migrates through the soil pores toward the extraction vents, VOCs are volatilized, transported out of subsurface soil, collected above ground, and, if necessary, treated before release to the atmosphere. SVE system performance depends on properties of both the soil (air permeability, bulk density, porosity, and moisture content) and the contaminants (vapor pressure, water solubility, and sorption properties).

The low air permeability of the targeted subsurface soil at the Site was believed to limit the applicability of SVE without enhancements. Used in conjunction with technologies that enhance permeability or volatility, the potential effectiveness of SVE can be improved and may become a more viable and cost effective remedial alternative for the removal of VOC contamination in the unsaturated zone.

Pneumatic fracturing is a commercially available, patented technology which enhances the in-situ removal and treatment of volatile organic compounds by increasing the air permeability in soil and rock formations. The principal objectives of pneumatic fracturing are reduction in treatment time and extension of available technologies to more difficult geologic conditions. Pneumatic fracturing has been successfully integrated with in-situ treatment technologies such as vapor extraction, bioremediation and ground water contaminant recovery.

Pneumatic fracturing involves the injection of pressurized air into low-permeable soil to extend existing fractures and to create a secondary network of conductive subsurface fissures and channels. If successful, the enhanced network of fractures increases the exposed surface area of the contaminated soil, as well as its permeability to liquids and vapors, thus creating pathways that enhance the soil vapor extraction (SVE) process.

There are several characteristics that were evaluated during the testing. A characteristic of a formation for effective contaminant removal is its natural bulk air permeability. Airflow rates correlate directly with the bulk air permeability. A quantitative comparison of airflow rates before and after fracturing provides an indication of the relative changes due to fracturing. The radius of vacuum influence during permeability testing demonstrates the degree of influence of the SVE system. Pre- and post-fracture vacuum influences are compared to evaluate the effect of fracturing.

Contaminant mass removal is determined by monitoring the extraction flow rates and VOC concentrations at specific times during permeability testing. Vapor samples were collected and analyzed hourly during the pre-fracture permeability test and six times per day during the post-fracture permeability test. Total VOC concentrations in the vapor samples were recorded with a hand-held HNU Model DI-101 Data Logging Photoionization analyzer. This information was used for evaluating the rates of contaminant removal by the SVE system before and after fracturing.

Fracture propagation is a function of the natural stresses and strains in the formation and the effective rate of "leak-off" of the gas into the formation. Pressure influence at surrounding monitoring wells was monitored during fracturing so that the effective radius of fracture influence could be determined. The paths of fracture propagation/creation are used to verify the horizontal extent of permeability change, if any. Through the use of monitoring points screened within the targeted fracture zone and located at varying radial distances from the fracture well, an assessment of the induced fracture network can be accomplished. Measurement of ground surface heave or "ground uplift" during fracture injection is utilized to determine fracture orientation and distance for shallow pneumatic fracture applications. Using a surveying transit and a graduated tape that is attached to a pylon located at the fracture well, measurement of the ground deflection can be monitored during each pneumatic injection. The maximum amount of upward motion (surface heave) and final ending height (residual heave) is measured in centimeters and recorded. The ground surface heave provides direct evidence of fracture propagation and direction.

2

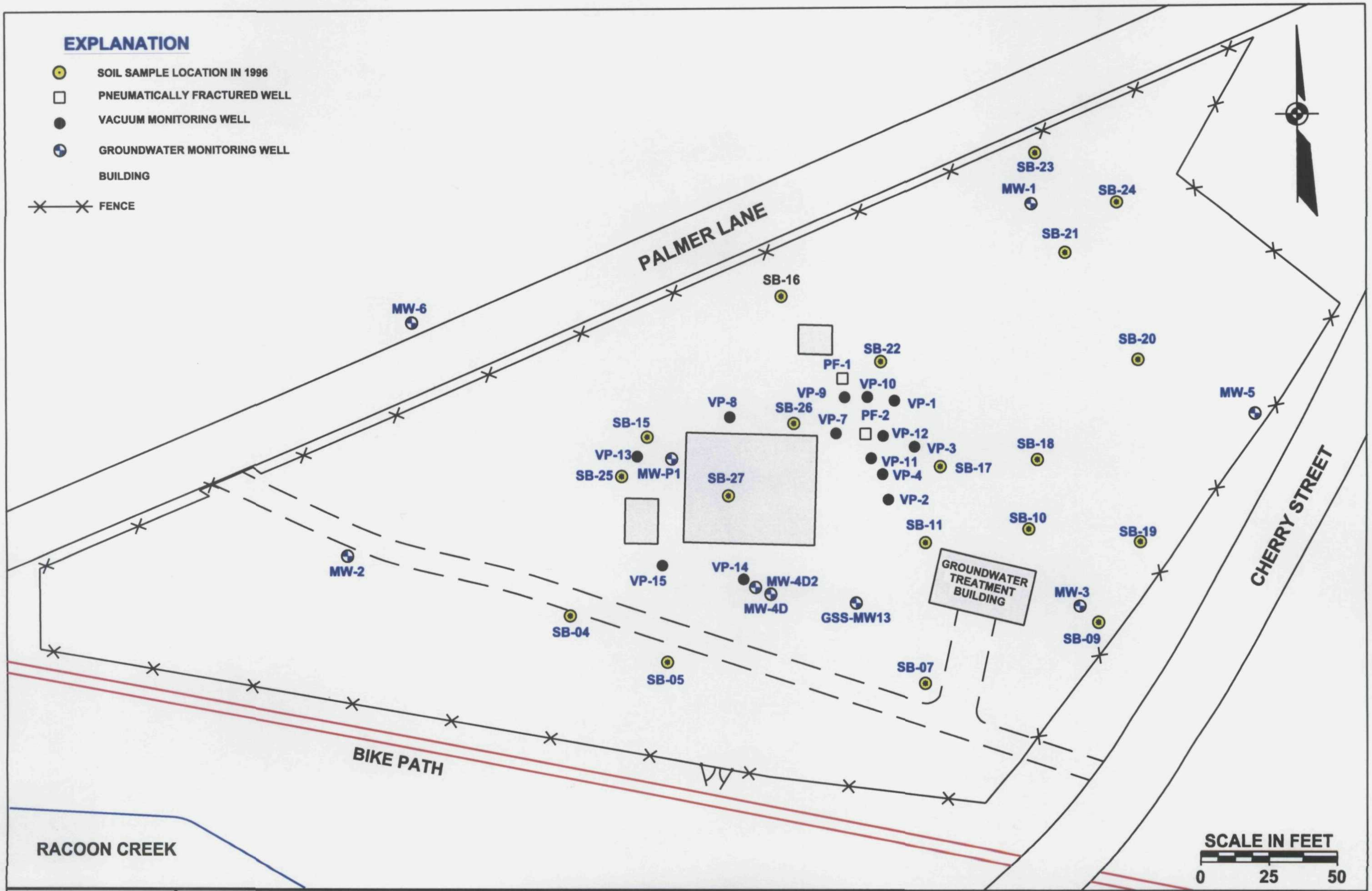
# Section Two

## 2.0 PILOT TEST VACUUM MONITORING AND EXTRACTION WELLS

Fifteen vacuum monitoring wells and two pneumatc fracture wells were installed in the pilot test area. Five existing groundwater monitoring wells with screen exposed above the water table were also used during the course of pilot testing (Figure 2). Nine vacuum monitoring wells were installed within the clay unit pilot test area east of the warehouse building to monitor both pressure and extraction influence within the targeted fracture zone. The lithology observed during the drilling consisted of between 7 and 12 feet of clay-rich materials underlain by poorly sorted medium- to fine-grained sand and gravel. Vacuum monitoring wells are numbered VP-1, VP-2, VP-3, VP-4, VP-7, VP-9, VP-10, VP-11, and VP-12 (Figure 3).

The wells were constructed by first drilling an 8.25-inch-diameter boring to the target depth and then inserting a 2-inch, schedule 40 PVC well screen (0.02 slot). The screened interval was selected based on the specific stratigraphy in the boring. A cross section location map is provided as Figure 4. The screen intervals and the lithologic unit in which they are screened are provided on Figure 5. Lithologic cross sections are provided as Figures 6, 7, and 8. No. 4 sand was used to fill the annular space of the screened interval. A bentonite/Portland cement mixture was placed around the riser pipe to seal off the screened interval. Monitor well construction details are provided on well logs that are located in Appendix A of the ARS Report (Appendix A). During the installation of monitoring wells VP-1 through VP-9, continuous split-spoon sampling was conducted for the entire boring. The soil samples were used for geologic logging purposes and screened with a portable PID (HNU Model DL-101) for VOC concentrations.

Four wells were drilled to aid in the evaluation of the sand unit. Vacuum monitoring well VP-8 was drilled to the water table and screened through the entire sand section from a depth of 5 to 20 feet bgs. A second well, VP-13, was drilled on the west side of the building to evaluate the shallow portion of the sand unit and two more wells, VP-14 and VP-15, were drilled to the south of the building.

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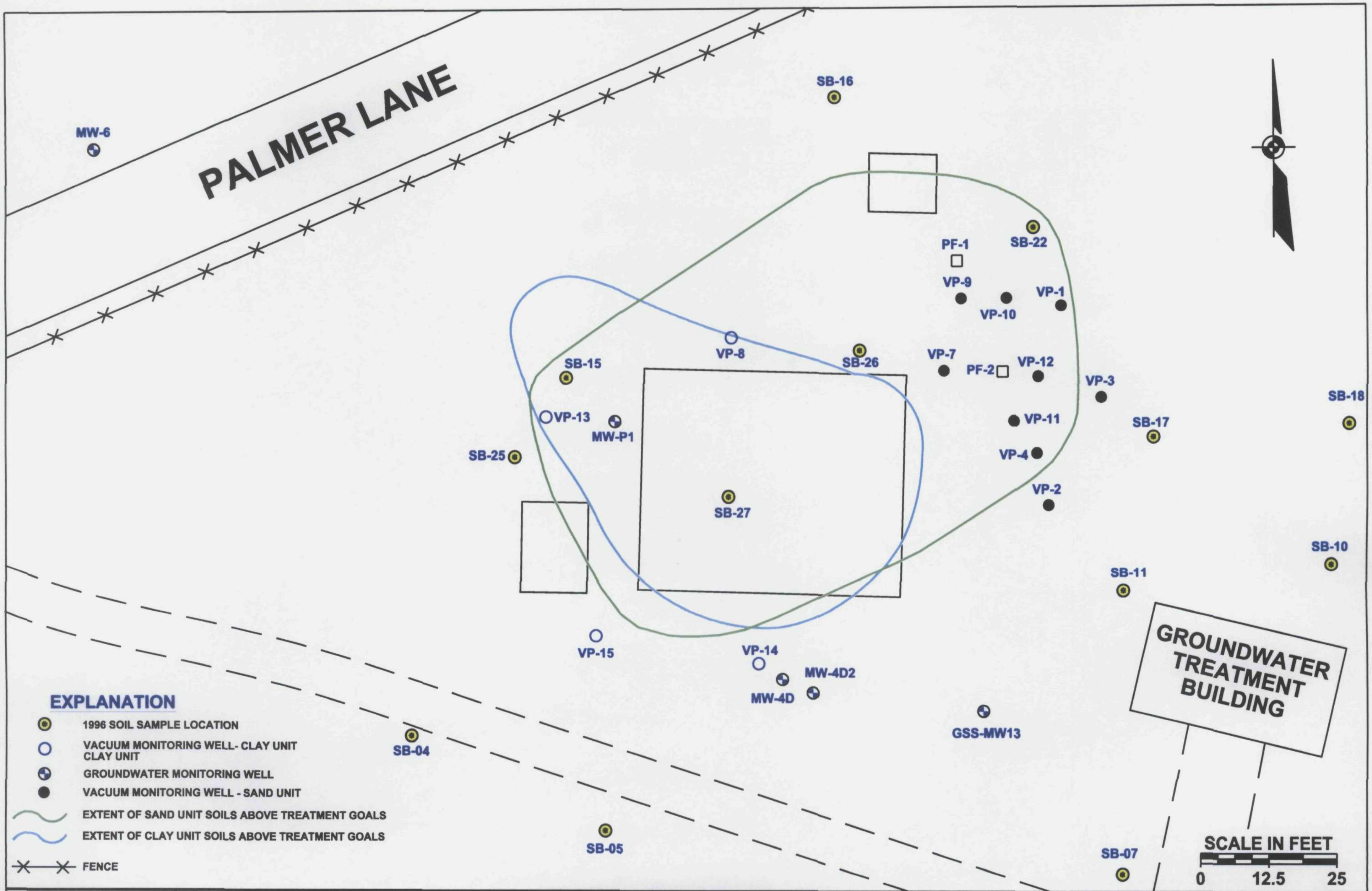


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GRANVILLE SOLVENTS SITE

# SOIL TREATMENT AREAS

GRANVILLE, OHIO

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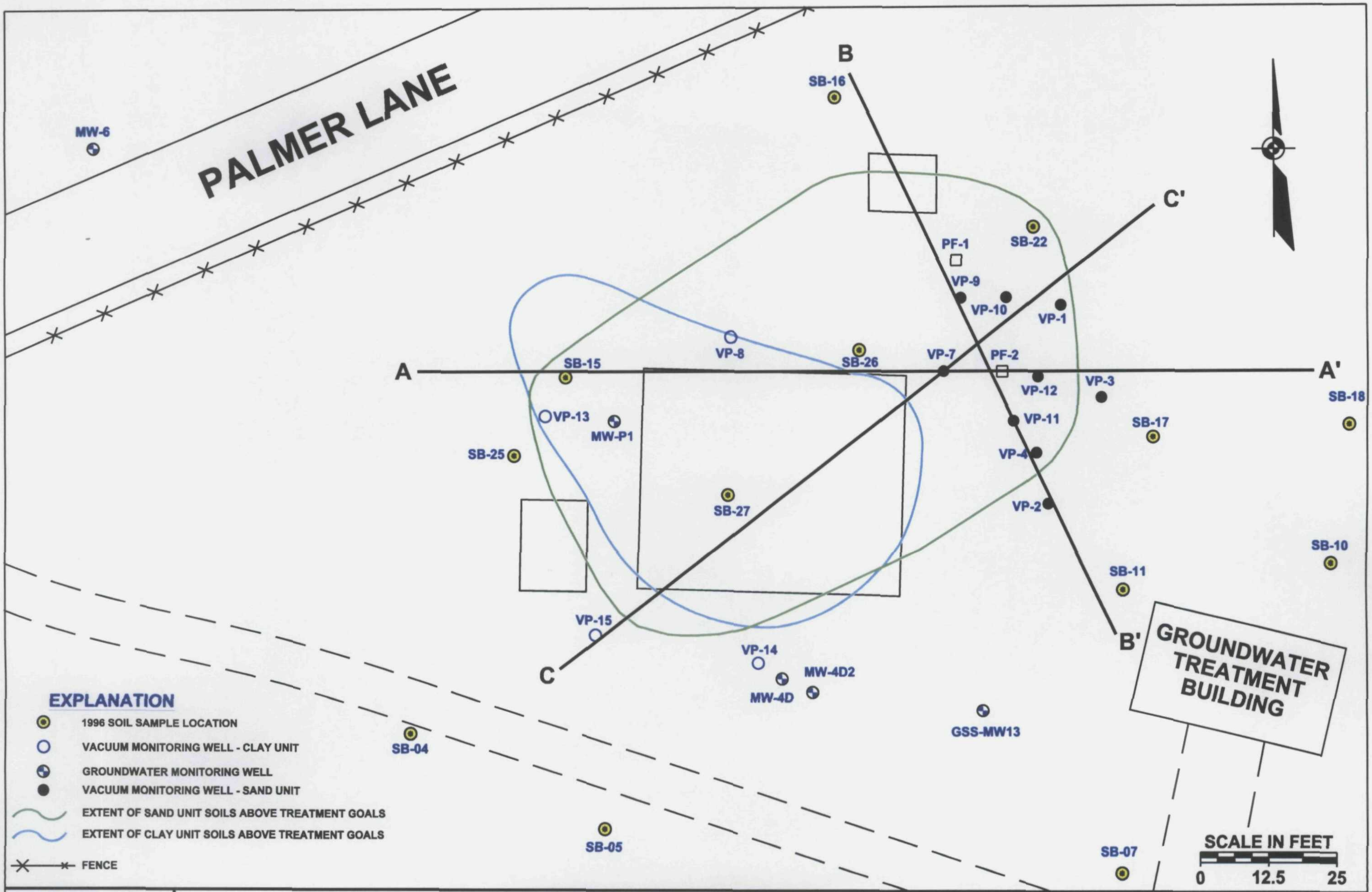


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# CROSS SECTION LOCATION MAP

GRANVILLE, OHIO

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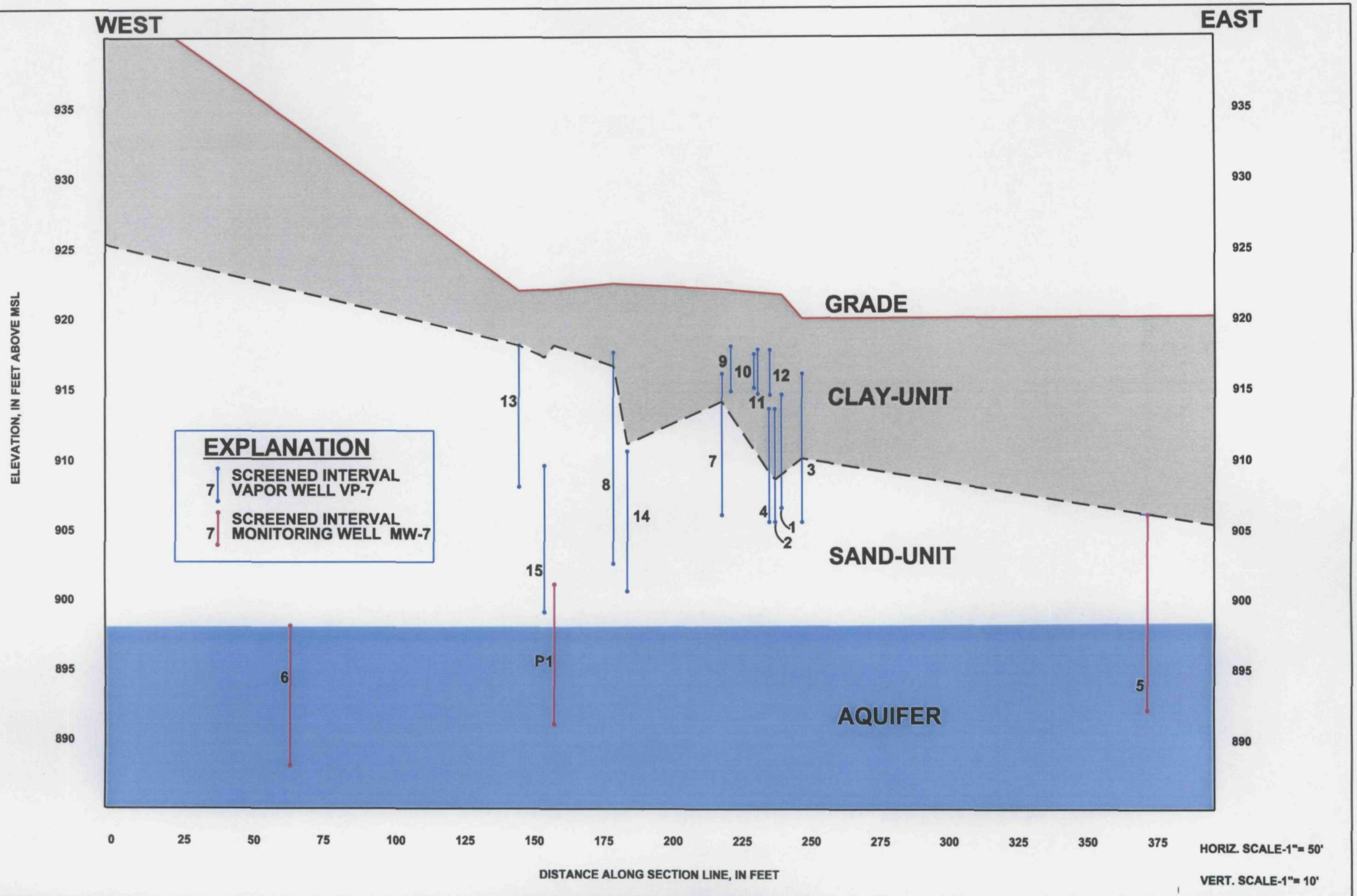


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**SCREEN INTERVALS**
**MONITORING WELL**
GRANVILLE, OHIO

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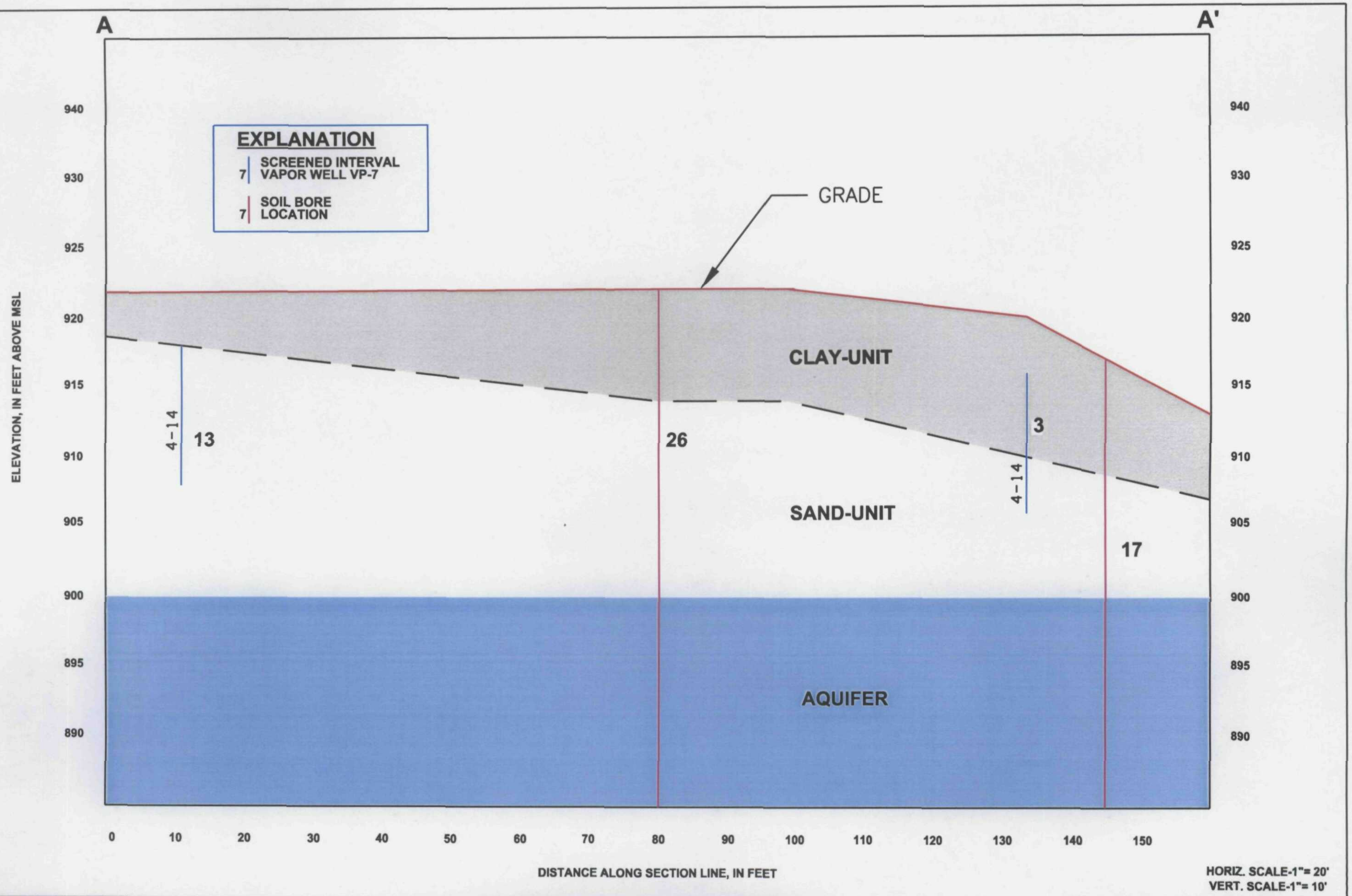


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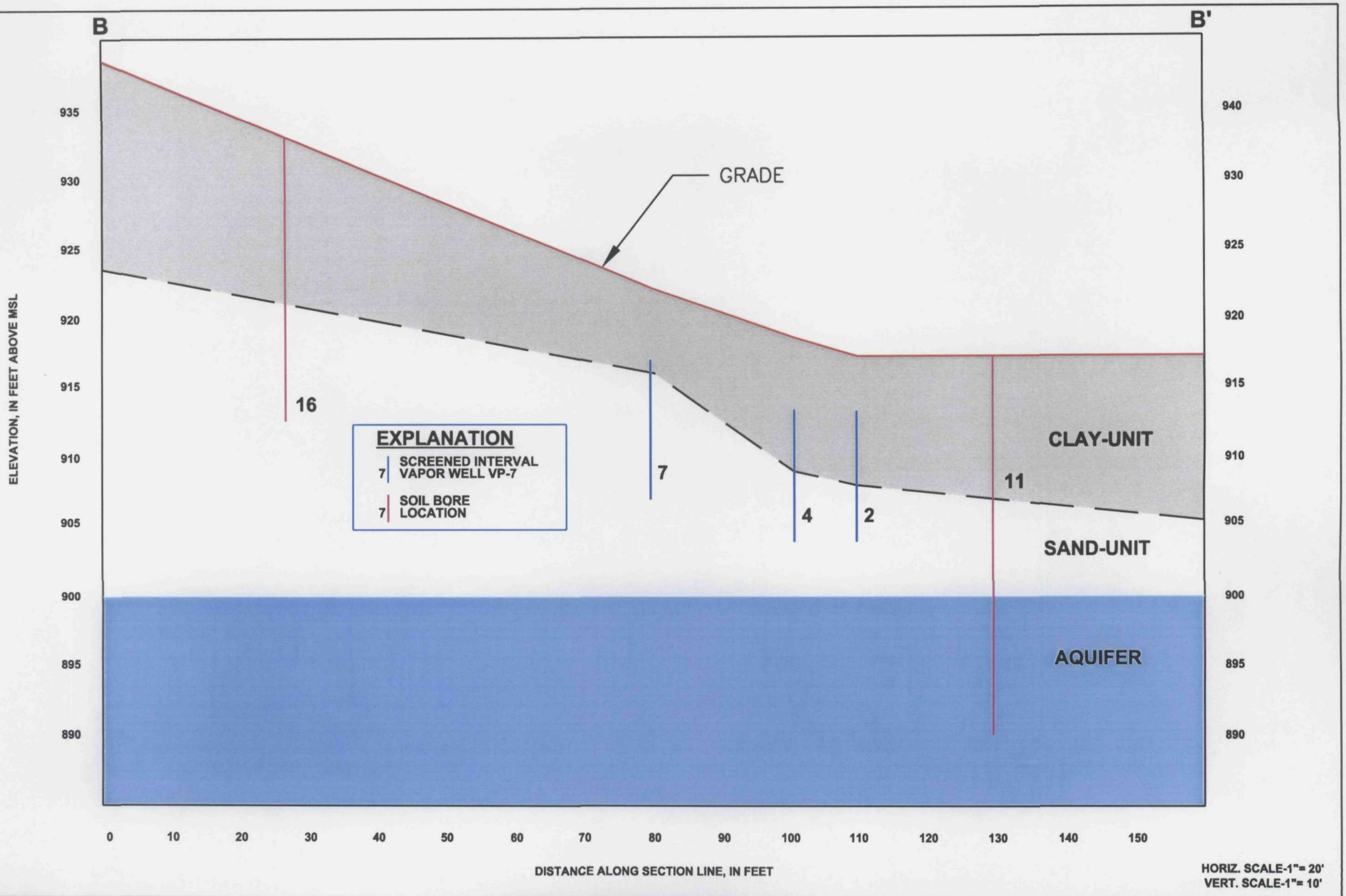


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# CROSS SECTION B-B'

GRANVILLE, OHIO

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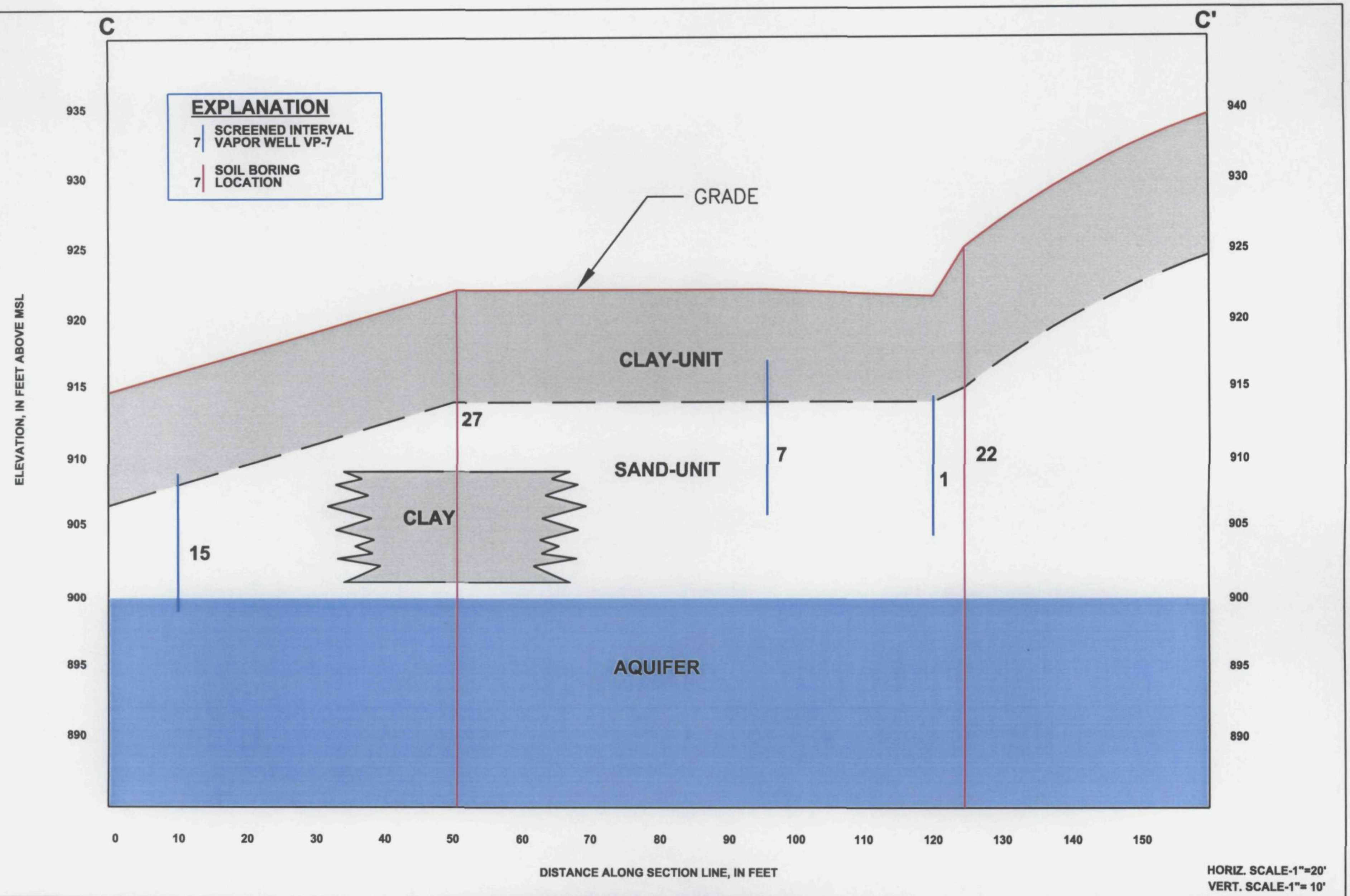


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| Metcalf & Eddy | GRANVILLE SOLVENTS SITE<br>**CROSS SECTION C-C'**<br>GRANVILLE, OHIO | Project Number<br>025508 | |
| | | File Name<br>25508XSECTC-C' | Figure<br>8 |

Two pneumatic fracture wells, designated PF, were installed within the pilot test area (Figure 2). Previous site investigations have identified the surface material within the targeted fracture interval (approximately 5 to 15 feet) to consist primarily of silt-rich clay. Based upon this information, it was anticipated that the two 4.75-inch-diameter borings would be advanced to an approximate depth of 15 feet below ground surface (bgs) utilizing solid stem augers to accommodate the pneumatic fracture tooling. Because the sand unit was encountered at an elevation higher than expected, the fracturing wells were terminated at shallower depths, above the sand zone (PF-1 at 9.5 feet bgs and PF-2 at 7.5 feet bgs).

The consistency and cohesiveness of the clay unit soils permitted the two borings to remain open for the duration of the pre-fracture permeability tests and the pneumatic fracture operations. Once the fracture applications were completed, both borings were converted to 2-inch, schedule 40 PVC soil vapor extraction wells.

The pilot test was conducted as two distinct tests, differentiating the clay unit, located from the surface to a depth of approximately ten feet below grade, from the sand unit, located below the clay unit. The equipment used for the pilot test was different for each pilot test. ARS Technologies provided a skid-mounted, high-vacuum low-flow unit for the initial clay unit test. Metcalf & Eddy provided a separate low-vacuum high-flow unit for the sand unit test.

3

# Section Three

## 3.0 CLAY-UNIT TESTS

Several soil vapor extraction tests were conducted on the clay-unit soils in the area of soil impact. The objectives of the testing were to determine the following:

- Natural or pre-fracture baseline bulk air permeability and mass removal rates;
- Pressure requirements for fracture initiation and maintenance;
- Extent of fracture propagation and orientation; and
- Post-fracture bulk air permeability and contaminant mass removal rates.

The clay-unit tests were conducted between April 29, 2000, and May 31, 2000. The tests included the following:

1. a pre-fracture permeability test of well VP-10,
2. soil fracturing tests of PF-1 and PF-2,
3. a post-fracture permeability test of well VP-10,
4. post-fracture permeability tests of wells PF-1 and PF-2,
5. a long-term vapor extraction test of wells PF-1 and PF-2, and
6. an air injection test for wells PF-1 and PF-2.

A detailed report (provided in Appendix A) covering tests 1 through 5 identified above, was prepared by Accutech Remedial Systems, Inc. (ARS). ARS was present during the installation of the VP well network, conducted the fracturing of wells PF-1 and PF-2, and conducted portions of the air permeability tests for the clay-unit.

A summary of the methods results and conclusions of these tests is provided in the following subsections. Details of specific tests are provided in Appendix A.

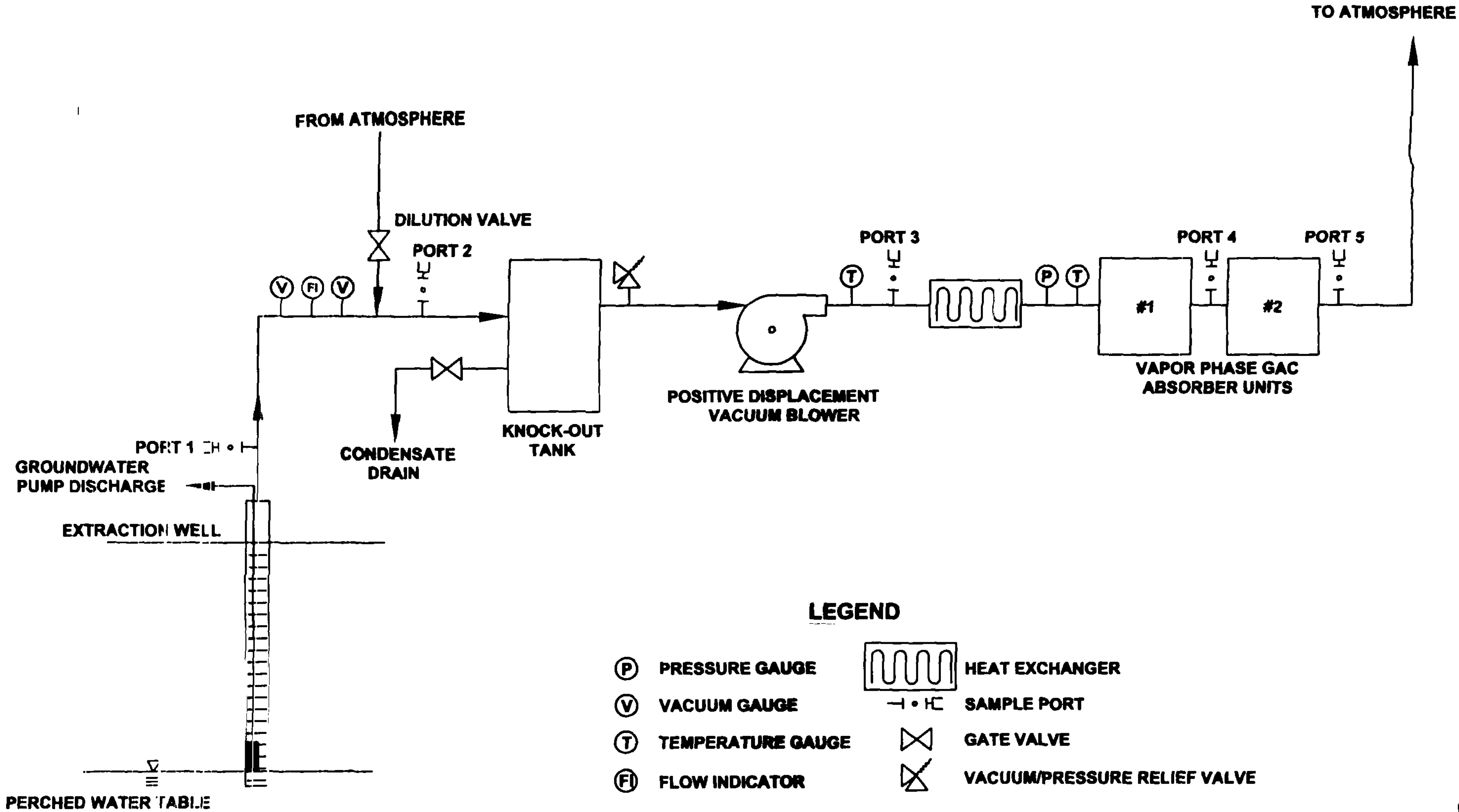
## 3.1 CLAY-UNIT TEST METHODS

All of the tests performed on the clay-unit utilized the same equipment and instruments. The equipment used to extract soil gas from the clay-unit and to inject atmospheric air into given wells consisted of the following primary components: (1) a positive displacement blower, (2) a vacuum relief valve, (3) a dilution valve, (4) a knock-out tank, (5) a pressure relief valve, (6) a heat exchanger, and (7) two granular activated carbon filters in series. A process schematic drawing of the vapor extraction unit is provided as Figure 9.

During the vapor extraction test, the blower pulls gas from the piping and the well creating a partial vacuum within the clay soils surrounding the extraction well. The extracted soil gas moves through the knock-out tank where liquid water, if present in the soil gas, is removed. A dilution valve between the wellhead and the knock-out tank provides a means for controlling the level of vacuum that is applied to the well and consequently the quantity of soil gas that is extracted. The blower adds heat to the soil gas, some of which is removed on the outlet side of the blower by a heat exchanger. The cooled soil gas is treated using granular activated carbon to remove volatile organic compounds present in the soil gas.

The blower used for this test was capable of approximately 120 scfm at free flow (no vacuum or pressure), and was capable of supplying lesser flow rates at vacuum or pressure up to approximately 12 inches of mercury.

Various gauges and ports are included with the vapor extraction unit to allow the monitoring of flow, vacuum, and temperature, and to allow the collection of soil gas samples (Figure 9). Exhaust from the vapor extraction unit was directed to carbon units for treatment prior to release to the atmosphere.

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| M&E Metcalf & Eddy | GRANVILLE SOLVENTS SITE<br>**CLAY-UNIT TEST SOIL VAPOR EXTRACTION PILOT UNIT PROCESS SCHEMATIC**<br>GRANVILLE, OHIO | Project Number 025508<br>File Name 25508CPID | Figure 9 |

During the extraction tests conducted on PF-1 and PF-2, pumps were used to remove water that was brought into the wells while vacuum was applied. Water extracted by the pumps was transferred to the groundwater treatment system in the adjacent building where it was treated prior to release to Raccoon Creek.

During the air injection tests, exchanging the piping connections to the intake and discharge ports of the blower reversed the flow direction. Atmospheric air was then pumped into the injection well.

The instruments used for monitoring the clay-unit tests included the manual gages illustrated on Figure 9 and the following additional equipment:

| | |
|---|---|
| • Photoionization detector | HNU Model D1-101 Photoionization Analyzer |
| • Digital manometer (0 to 20 in. w.c.) | Dwyer Instruments |
| • Digital manometer (0 to 200 in. w.c.) | Dwyer Instruments |
| • Flow meter | Accutubes (1.5 and 2 inch) |
| • Magnehelic gages | Dwyer Instruments |

The methods used to conduct the tests of the clay-unit are provided in Appendix A except for the air injection tests for wells PF-1 and PF-2. Methods used to conduct this test are provided below.

## 3.2 AIR INJECTION TEST OF WELLS PF-1 AND PF-2

An air injection test of wells PF-1 and PF-2 was started following the long term soil gas extraction tests. Air injection testing began on May 26, 2000, and continued through May 31, 2000. The purpose of the testing was to determine if higher flow rates could be obtained in the wells by injecting air rather than withdrawing air. A secondary purpose of the test was to provide a visual method of determining the radius of pore fractures accessed by the fracture wells that reached the ground surface.

Air was injected into the wells at a pressure of approximately 70 inches. Water column and pressure readings were obtained from clay-unit vapor monitoring probes VP-9, VP-10, VP-11, and VP-12. Injected air flow rates were obtained using the Accutube flow measurement tube. Flow measurements were obtained over the duration of the test to determine if the flow rate increased over time as air was injected into the wells.

The last step of the air injection test was a visual check of the radius of fractures and channels through which the air made its way to the ground surface from the locations of the injection wells. A dilute soap solution was sprayed onto the ground surface in the area surrounding the two air injection wells (PF-1 and PF-2). Air escaping from the ground surface through fractures and other air channels could then be visually observed at the surface.

## 3.3 CLAY-UNIT TEST RESULTS

The complete data sets from the tests conducted in the clay-unit are provided in Appendix A. Detailed discussions of the results and the methods used to calculate permeability and other parameters are provided in Appendix A. A summary of the tests results is provided below.

### 3.3.1 Clay-Unit Air Permeability Testing

The following air permeability tests were conducted: (1) a pre-fracture test of VP-10, a post-fracture test of VP-10, and post-fracture permeability tests of PF-1 and PF-2. The radius of influence, permeability, air flow rate, and mass removal rate results obtained from these tests are provided in Table 2.

**TABLE 2**

**RESULTS OF CLAY-UNIT PERMEABILITY TESTS**

| Extraction Well | Applied Vacuum (In. Hg) | Permeability (Darcy) | Radius of Influence (Feet) | Air Flow Rate (scfm) | Mass Removal (lb/day) |
|---|---|---|---|---|---|
| VP-10 (pre-fracture) | 10 | 3.87 | 18.1 | 27.4 – 33 | 1.1 |
| VP-10 (pre-fracture) | 12.5 | 2.83 | 19.7 | 25 – 31 | 2.0 |
| VP-10 (post-fracture) | 10 | 4.48 | 18.0 | 36.8 – 39.7 | 0.55 |
| VP-10 (post fracture) | 12 | 3.36 | 16.4 | 37.1 –38.9 | 0.42 |
| PF-1 (post-fracture) | 10 | 5.47 | 16.4 | 31.8 – 35.0 | 0.08 |
| PF-1 (post-fracture) | 11 | 5.17 | 21.1 | 34.5 – 35.8 | 0.06 |
| PF-2 (post-fracture) | 10 | 5.12 | 16.4 | 30.2 – 34.4 | 1.23 |
| PF-2 (post-fracture) | 11.5 | 4.14 | 16.4 | 32.0 – 34.1 | 1.81 |
| PF-1 & PF-2[a] (long-term) | 10 | 12.9 | 24.6 | 30.8 – 76.7 | 1.0 |
| PF-1 & PF-2[b] (long-term) | 10 | 13.7 | 32.8 | 30.8 – 76.7 | 1.0 |

[a] Effective radius of influence for PF-1 was calculated using PF-1 and closest monitoring wells, but was determined during a period when both PF-1 and PF-2 were extracting soil gas.

[b] Effective radius of influence for PF-2 was calculated using PF-2 and closest monitoring wells, but was determined during a period when both PF-1 and PF-2 were extracting soil gas.

The air permeability tests conducted at VP-10 indicate that only a small increase in permeability occurred at this well following the fracturing process. However, a rainfall event occurred just after the fracturing process was completed. The rainfall would likely have filled some of the voids produced by the fracturing process. The above rainfall event and subsequent rainfall events made direct comparison of post-fracture permeability to pre-fracture permeability unreliable.

Direct comparison between the permeability of VP-10 and the fractured wells, PF-1 and PF-2, was also complicated by the rainfall events that occurred following the fracturing. The permeability values determined for PF-1 and PF-2 were slightly higher than the permeability determined for VP-10 before and after fracturing.

During the long-term test of PF-1 and PF-2, the permeabilities calculated for these wells from data obtained near the end of the long-term testing indicated that the permeability had increased at these wells by nearly three times. This increase could be due in part to the removal of some of the water added to the soil voids during the rainfall events. The increase is also due in part to the drying of the soils by the air flow. Soil drying tends to increase secondary porosity in the soil through the creation of additional fractures and the enlargement of existing fractures. Drying also opens some of the primary soil porosity to flow. This drying generally will occur under long-term operation of most SVE systems. The lower the relative humidity of the air moving through the soil, the more rapidly soil drying occurs.

The bores for the fractured wells were smaller than the bore for VP-10 (4.75 inches versus 8 inches). A smaller well diameter will typically result in lower air flow rates from the well, given similar applied vacuum and similar soils. The results indicate that the air flow rates for PF-1 and PF-2 were similar to, and slightly greater than, the flow rates for VP-10.

### 3.3.2 Soil Fracturing Tests

Three methods were used to aid in determining the influence of fracture propagation at PF-1 and PF-2 as the pressure was applied to the subsurface. These three methods include (1) the analysis of pressure transducer data and fracture initiation pressure data, (2) the analysis of pressure influence at adjacent monitoring wells, and (3) the observation of surface heave during and following pneumatic fracturing.

Pressure transducer data were collected during the pneumatic fracturing of PF-1. The data are plotted in Figure 5 of Appendix A. The plot does not indicate a distinct initiation pressure typically seen during fracture propagation. It is thought that the shallow depth at which the fractures were propagated contributed to a lack of a distinct initiation pressure indication in the plot. The maximum pressure held by the formation during the fracturing process was 92 pounds per square inch (psi) for PF-1 and 100 psi for PF-2.

All wells installed in the pilot test area were outfitted with pressure measuring devices that held the highest pressure obtained at each location. During fracturing of PF-1, only well PF-2 showed a pressure influence from the test (0.1 psi maximum). During fracturing of PF-2, only well VP-12 showed a pressure influence (0.25 psi). This indicates that significant pressure breakthrough did not occur at most monitoring wells.

Ground surface heave was measured during the pneumatic fracturing of PF-1 and PF-2. The ground surface at the wellhead and 11 feet from the wellhead were observed during the fracturing and after fracturing was complete. During the injection process, heave adjacent to the wells was 0.065 and 0.08 feet for PF-1 and PF-2, respectively, and 11 feet from the wells the heave was 0.02 and 0.03 feet, respectively. Residual heaves (after the fracturing process was complete) of 0.02 and 0.03 were measured adjacent to wells PF-1 and PF-2, respectively, and no residual heave was present 11 feet from the fracture wells.

One other method for determining fracture propagation is visual observation of "daylighting". Daylighting occurs when the injected air is seen penetrating the ground surface. It is observed as a puff of air and soil during the application of the pressurized air.

### 3.3.3 Soil Gas Extraction Rate During Long-Term Test

Wells PF-1 and PF-2 were both connected to the vacuum extraction system for the long-term test. The soil gas flow rate extracted from the two wells was observed to increase over time as the test continued. Figure 10 shows the long-term trend of flow increase over the 21 days of the long-term test. It is anticipated that this trend of increasing flow rate would have continued if the tests had been continued. The increase in flow rate is probably due to the removal of perched water and residual saturation from within the clay-unit and progressive drying of the soils.

### 3.3.4 Soil Gas PID Reading During Long-Term Test

PID measurements were taken periodically during the 21 days of the long term vapor extraction test of wells PF-1 and PF-2. Figure 11 provides a plot of the PID data obtained from the soil gas over the course of the long term test. As shown in Figure 11, the PID readings increased over the course of the test. This upward trend has been attributed to an improvement in air flow due to the drainage of water from fracture voids in the soil. It is also likely that some soil desiccation occurred in fractures and other voids which provides greater access to soil contaminants not residing directly on fracture surfaces.

**FIGURE 10**
**TOTAL FLOW RATE - LONG TERM CLAY UNIT TEST**

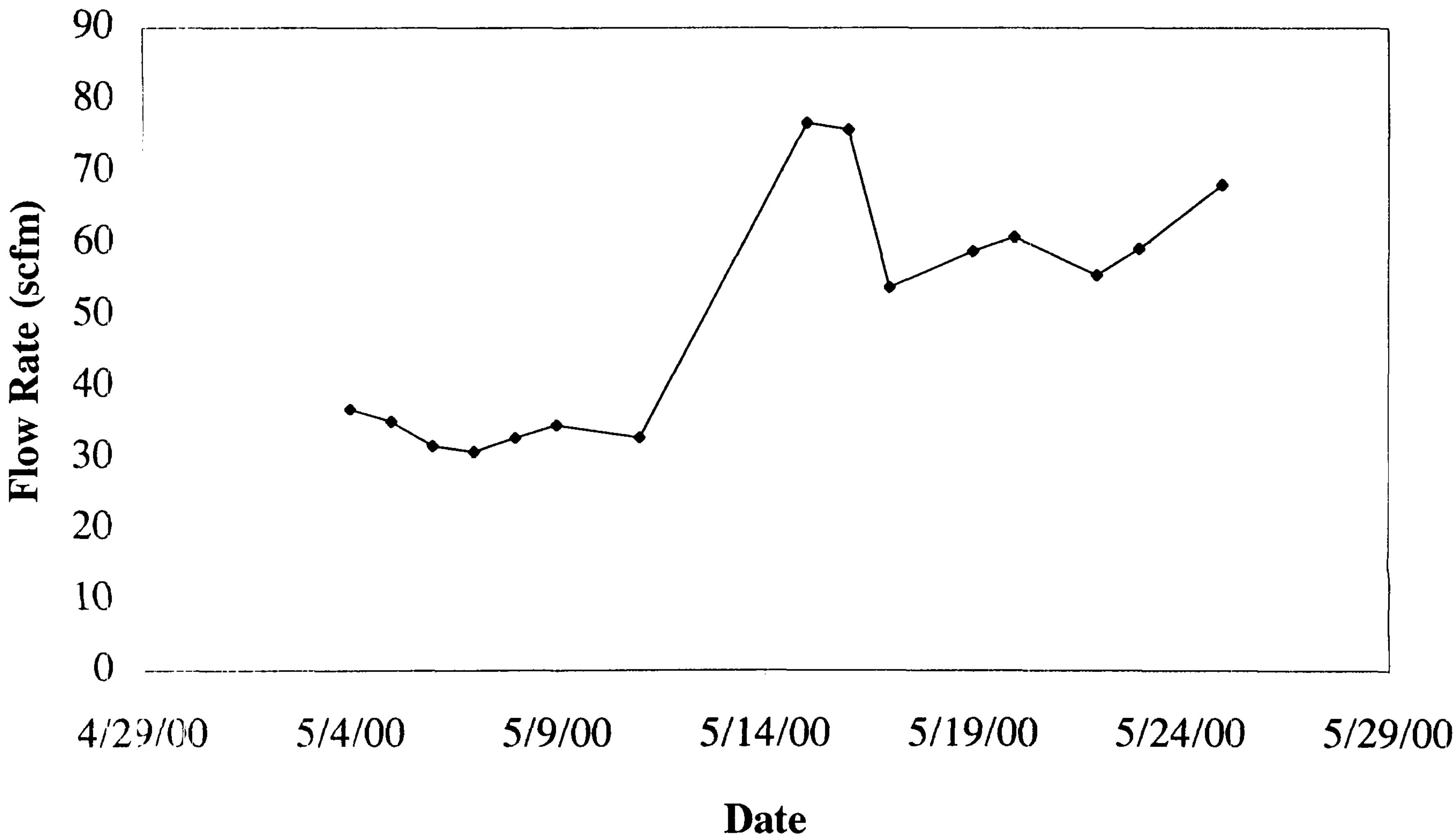
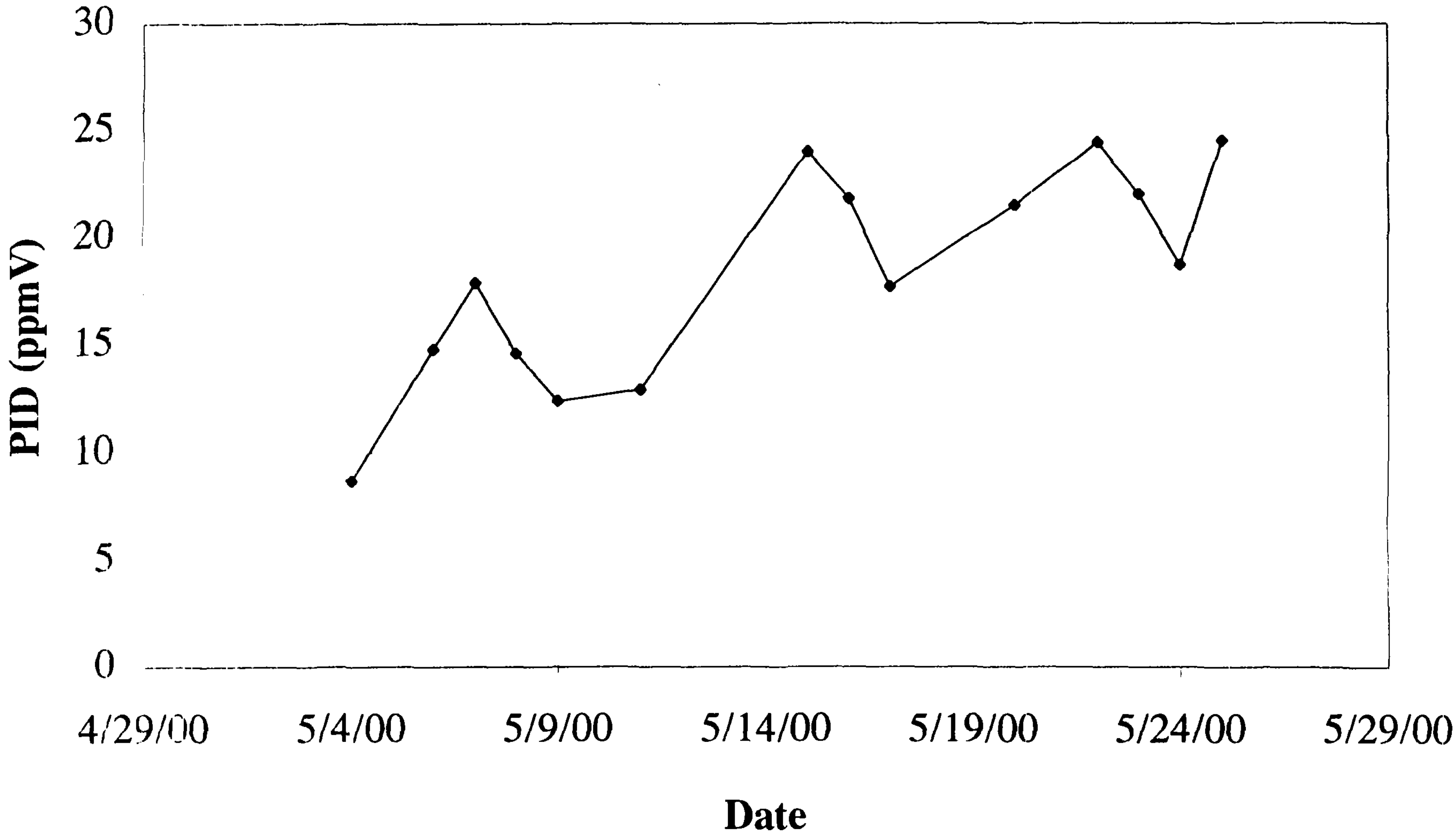


**FIGURE 11**
**PID MEASUREMENTS, LONG TERM CLAY UNIT TEST**



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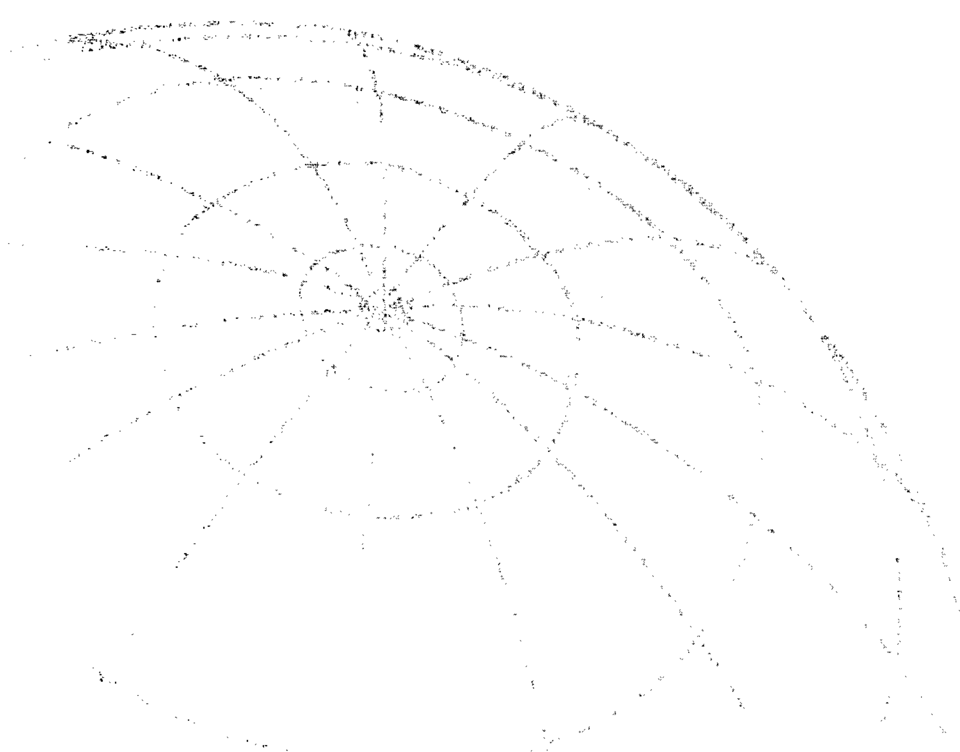


# Section Four

# 4.0 SAND UNIT TESTS

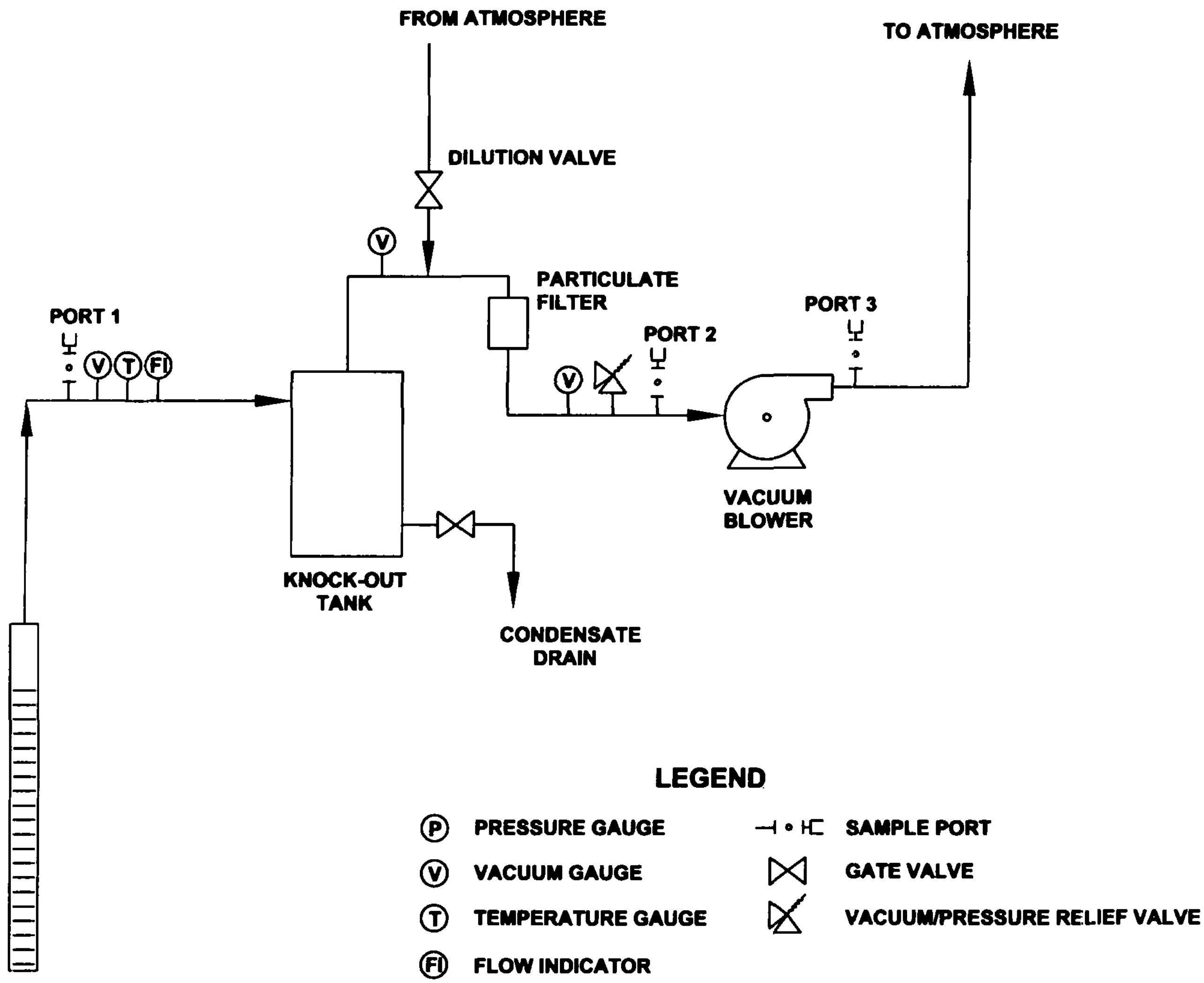
Several tests were conducted on the sand unit in the area of impacted soil. The following objectives were established for the sand unit testing:

- Determine if the unit was suitable for soil gas extraction without fracturing;
- Estimate the permeability of the unit;
- Estimate the volume of soil that could be effectively treated from a single extraction well;
- Establish design parameters for a full-scale SVE system targeting this unit (required well spacing, expected flow rate from single wells, required vacuum to attain desired flow rate, and expected VOC concentration for extracted soil gas).

Sand unit tests were conducted between May 4, 2000, and July 13, 2000. Tests conducted on VP-8 included a step test, steady state vacuum influence tests, a steady state air permeability test, several transient air permeability tests, and a long-term test to determine the expected VOC production rate from the extraction well. Tests conducted on VP-14 included a steady state radius of influence test. The methods, results and conclusions of these tests are provided in the following subsections. Details of specific tests are provided in Appendix B.

## 4.1 SAND UNIT TEST METHODS

All of the tests performed on the sand unit utilized the same equipment and instruments. The equipment used to extract soil gas from the sand unit and inject atmospheric air into the sand unit consisted of the following primary components: (1) a regenerative blower, (2) a vacuum relief valve, (3) a particulate filter, (4) a dilution valve, and (5) a knock-out tank. A process schematic drawing of the vapor extraction unit is provided as Figure 12.

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| | | File Name 25508PID | Figure 12 |

During the vacuum extraction test, the blower extracts gas from the piping and the well creating a partial vacuum within the sand unit. The soil gas moves through the knock-out tank where water that may be present in the soil gas is removed. A dilution valve downstream of the knock-out tank provides a means for controlling the vacuum that is applied to the well and consequently the quantity of soil gas that is extracted. The particulate filter traps soil and other particles that can be drawn into the system through the well or the dilution valve. The blower used for this test has a capacity of approximately 150 scfm when operating without restriction (no vacuum or pressure).

Various gauges and ports are included with the vapor extraction unit to monitor flow, vacuum, and temperature, and to collect soil gas samples (Figure 12). Exhaust from the vapor extraction unit can be directed to carbon units for treatment or can be discharged directly to the atmosphere. Based on measurements taken prior to the installation of this unit, the total VOC discharge from the unit was estimated to be less than 10 pounds per day making treatment of the exhaust unnecessary. Measurements after the start-up of this unit confirmed this estimate.

During the air injection tests, the flow direction is reversed by exchanging the piping connections to the intake and discharge ports of the blower. Atmospheric air is then pumped to the vapor well. The air injection mode was used to conduct the transient permeability tests, because it allowed the use of pressure transducers and rapid data logging equipment. The instruments used for conducting the sand unit tests included the manual gages shown on Figure 12 and the following additional equipment:

| | |
|---|---|
| • Photoionization detector | Thermo Environmental, Inc, OVM |
| • Digital manometer (0 to 20 in. w.c.) | Dwyer Instruments |
| • Digital manometer (0 to 200 in. w.c.) | Dwyer Instruments |
| • Flow meter | Velosicalc |
| • Pressure Transducers | In Situ, Inc. |
| • Data logger | In Situ, Inc. |

### 4.1.1 Step Tests

Step tests were conducted on wells VP-8 and VP-14. The purpose of the step tests was to establish a relationship between the vacuum applied to the well and the soil gas flow rate extracted from the well. The tests were conducted by applying three successive levels of vacuum to the wellhead. The highest vacuum applied was close to the maximum vacuum/flow rate that could be achieved from the well with the vacuum blower. The other two vacuum "steps" were lower than the maximum and were used to develop the vacuum/flow curve.

The vacuum data for the step tests were plotted against the air flow data and a line was drawn that provided a least squares best fit of the data points. Using the line, the expected flow rate can be estimated for a range of potential applied vacuum levels.

### 4.1.2 Steady State Vacuum Influence Test

Steady state vacuum influence tests were conducted on wells VP-8 and VP-14. The tests include applying a constant vacuum to the extraction well and allowing the sand unit soils to come to equilibrium with the applied vacuum. Following a period of time to allow the vacuum to equilibrate, all available monitoring wells are measured for vacuum to determine the area of vacuum influence. The area of vacuum influence is plotted and the vacuum contours within this area are drawn. To confirm the presence of vacuum influence at locations where only very low readings are obtained, the blower system is shut down and the measurements are repeated at the monitoring locations. If the repeat vacuum reading was reduced to zero following this procedure, an assumption is made that the vacuum observed was a result of the applied vacuum at the extraction well.

### 4.1.3 Steady State Air Permeability Tests

Steady state air permeability tests are conducted by applying a constant vacuum to the extraction well and allowing the soil to come to equilibrium (steady state) with the applied vacuum. Equilibrium was generally achieved in a relatively short time (within one hour), but the tests were run considerably longer to ensure that steady state conditions had been achieved.

Vacuum measurements were then obtained from all available monitoring points that were known to be screened within the lower sand. Based on the vacuum observed at the extraction well, the monitoring well and based on the distance from the extraction well to the monitoring well, air permeabilities were calculated from data from each monitoring well.

### 4.1.4 Transient Air Permeability Tests

Transient air permeability tests were conducted on all monitoring locations that consistently showed vacuum readings above .05 inches of water column. The tests were conducted by shutting down extraction from well VP-8 and allowing the vacuum in the sand unit to equilibrate to atmospheric pressure. A transducer was then attached to a monitoring well and connected to a data recorder. The vacuum was reapplied to well VP-8 at the same time that the data recorder began to record vacuum data at the monitoring well.

The data recorded by the data logger were then analyzed using methods developed for transient air permeability tests (see Appendix B). The flow rate obtained from the extraction well and the slope of the least squares best fit line for a plot of monitoring well vacuum versus the natural logarithm of time were used to calculate the air permeability of the sand unit. The methods presented in the *"Test Plan and Technical Protocol for Field Treatability Tests for Bioventing"* (AFCEE, 1992) were used for calculating permeability based on transient vacuum data.

### 4.1.5 Long-Term VOC Production Tests

Soil gas was extracted from VP-8 at a relatively constant rate for 40 days. During that period, the VOC content of the exhausted soil gas was tested regularly using a PID.

## 4.2 RESULTS OF THE TESTS CONDUCTED ON THE SAND UNIT

Figures 13 and 14 provide the results of the step tests conducted on wells VP-8 and VP-14, respectively. The flow rates achieved from each well are near the limit that can be observed for two-inch soil vapor extraction wells completed in a sand unit of this thickness. This indicates a relatively high permeability for the sand unit.

The slope of the vacuum observed versus flow rate line is steeper for well VP-14, indicating that the formation in the area of VP-14 is less permeable (or the sand unit is not as thick in this area). However, both wells show good air flow at relatively low vacuum. Figures 13 and 14 can be used to estimate the flow rate that can be obtained from these wells for a variety of applied vacuums.

The steady state radius of vacuum influence for well VP-8 is shown in Figure 15. The steady state radius of vacuum influence for well VP-14 is shown in Figure 16. The combined radii of vacuum influence for VP-8 and VP-14 easily covers the area where soil impact is above the clean-up goals established in the EE/CA (also indicated on Figures 15 and 16). It may be observed that the radius of influence of the wells is elongated in the axis parallel to Raccoon Creek. The areas of vacuum influence appear to overlap in the area beneath the warehouse building. However, air flow across the building from north to south appears to be restricted.

**FIGURE 13**
**STEP TEST RESULTS FOR WELL VP-8**

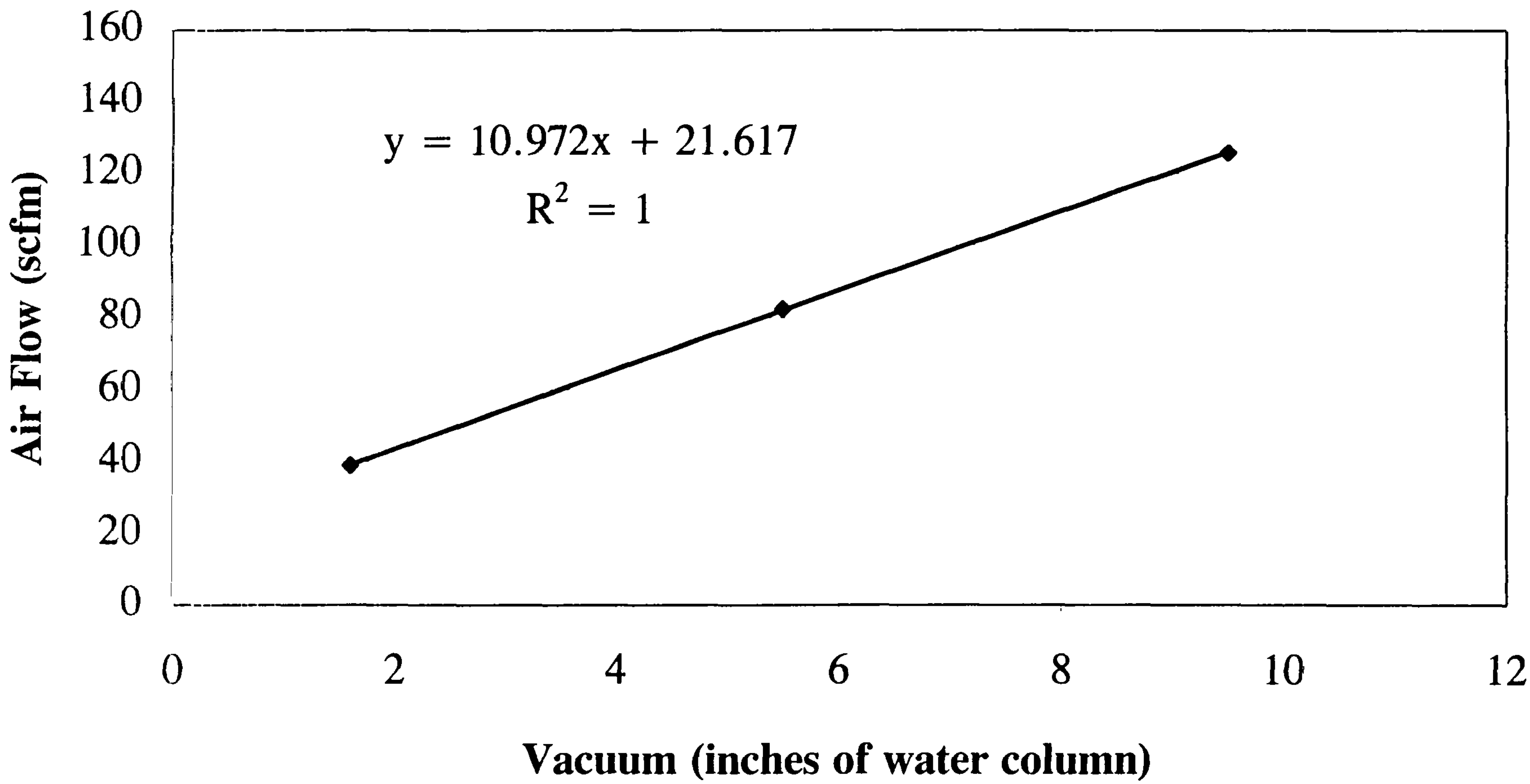
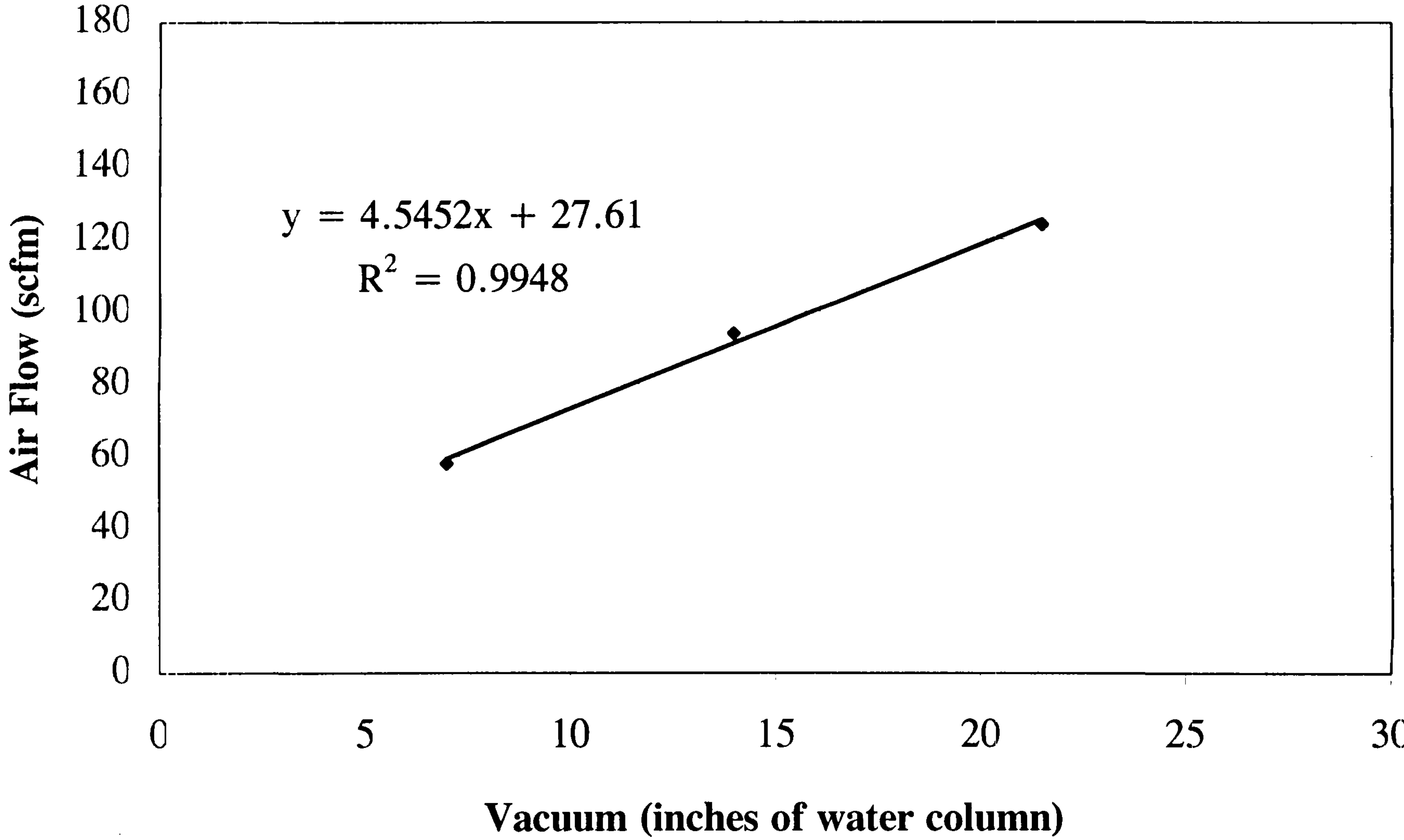
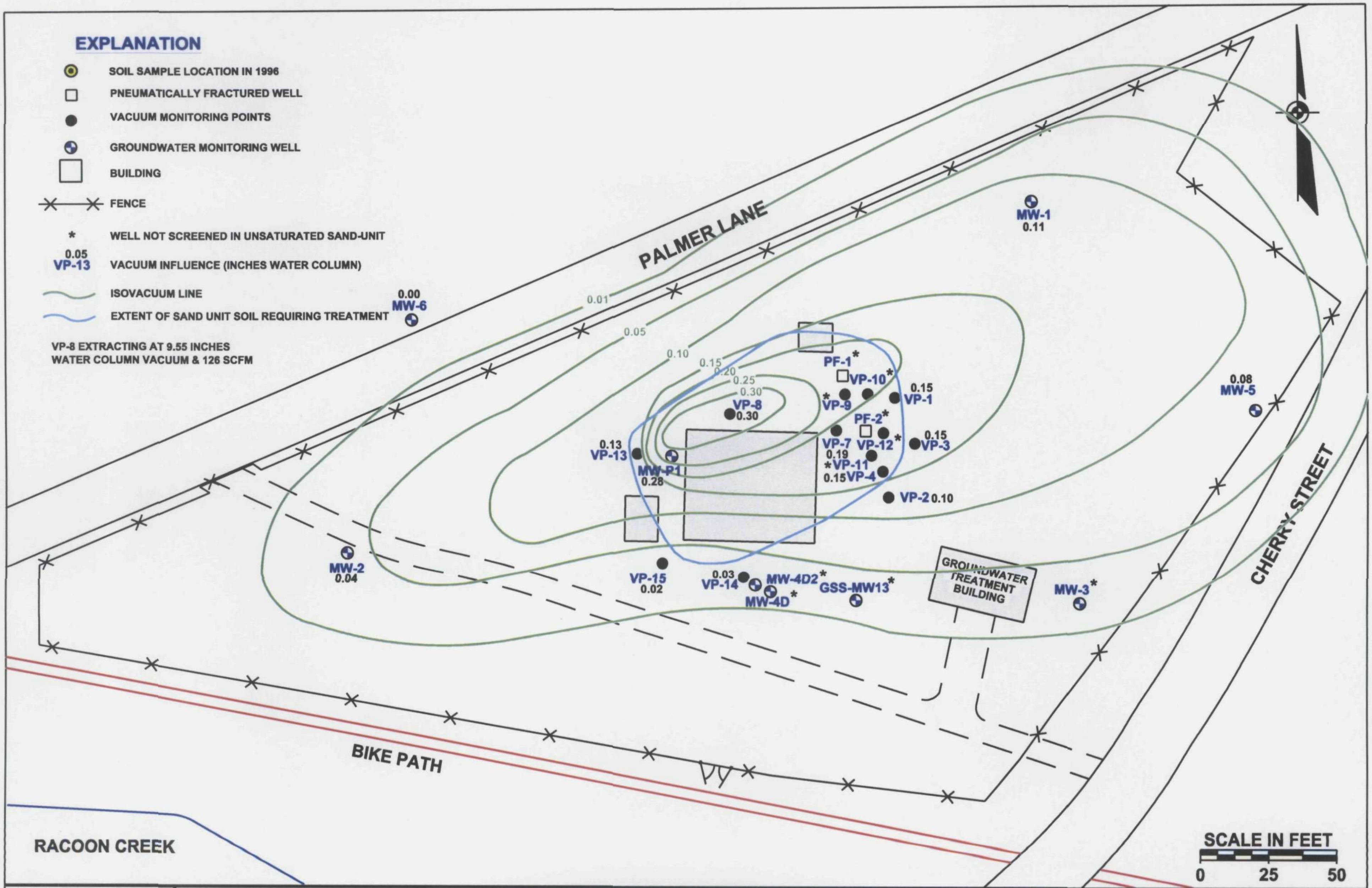


**FIGURE 14**
**STEP TEST RESULTS FOR WELL VP-14**



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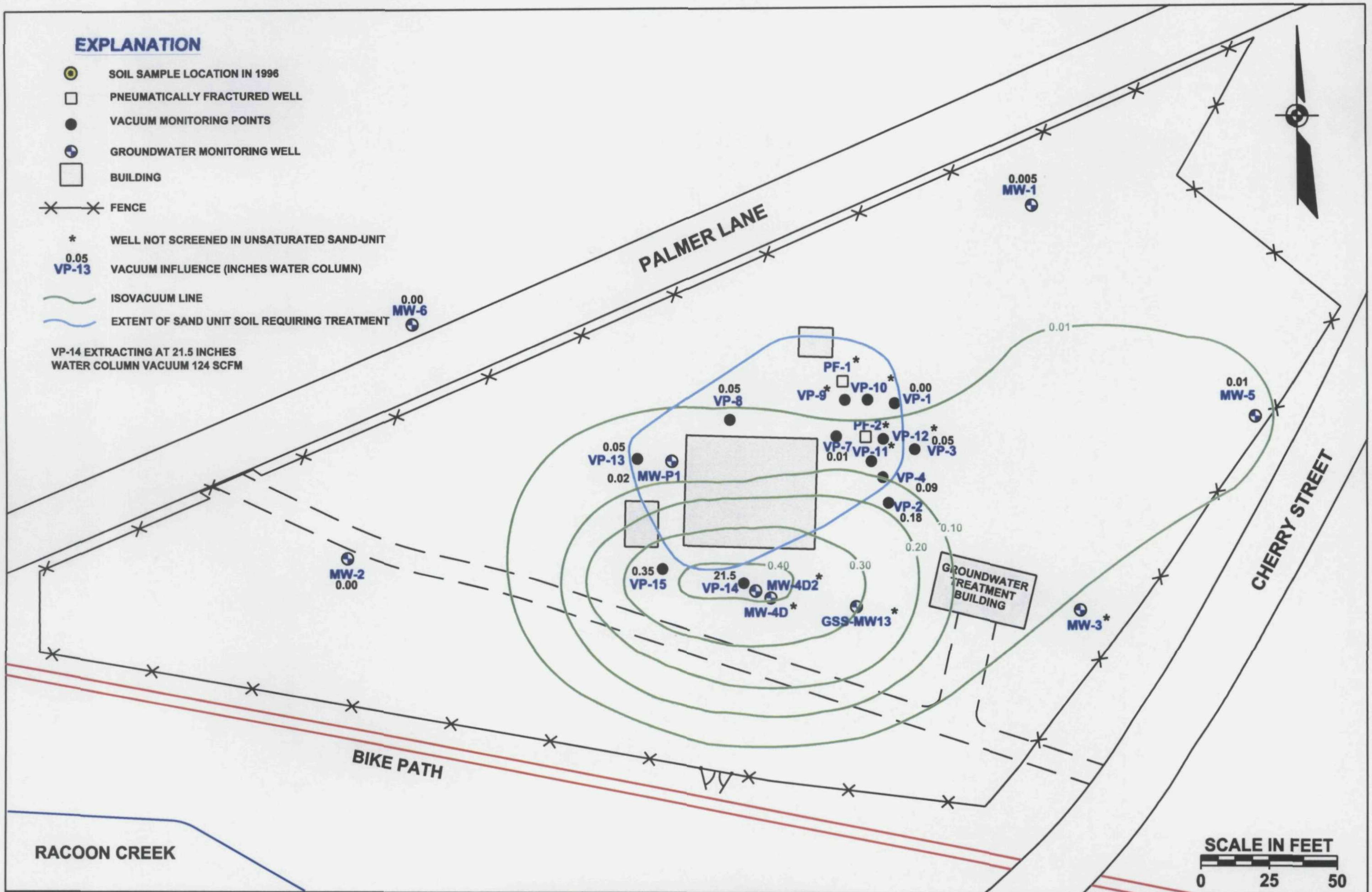


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**VP-14 7/12/00**

GRANVILLE, OHIO

| Project Number | |
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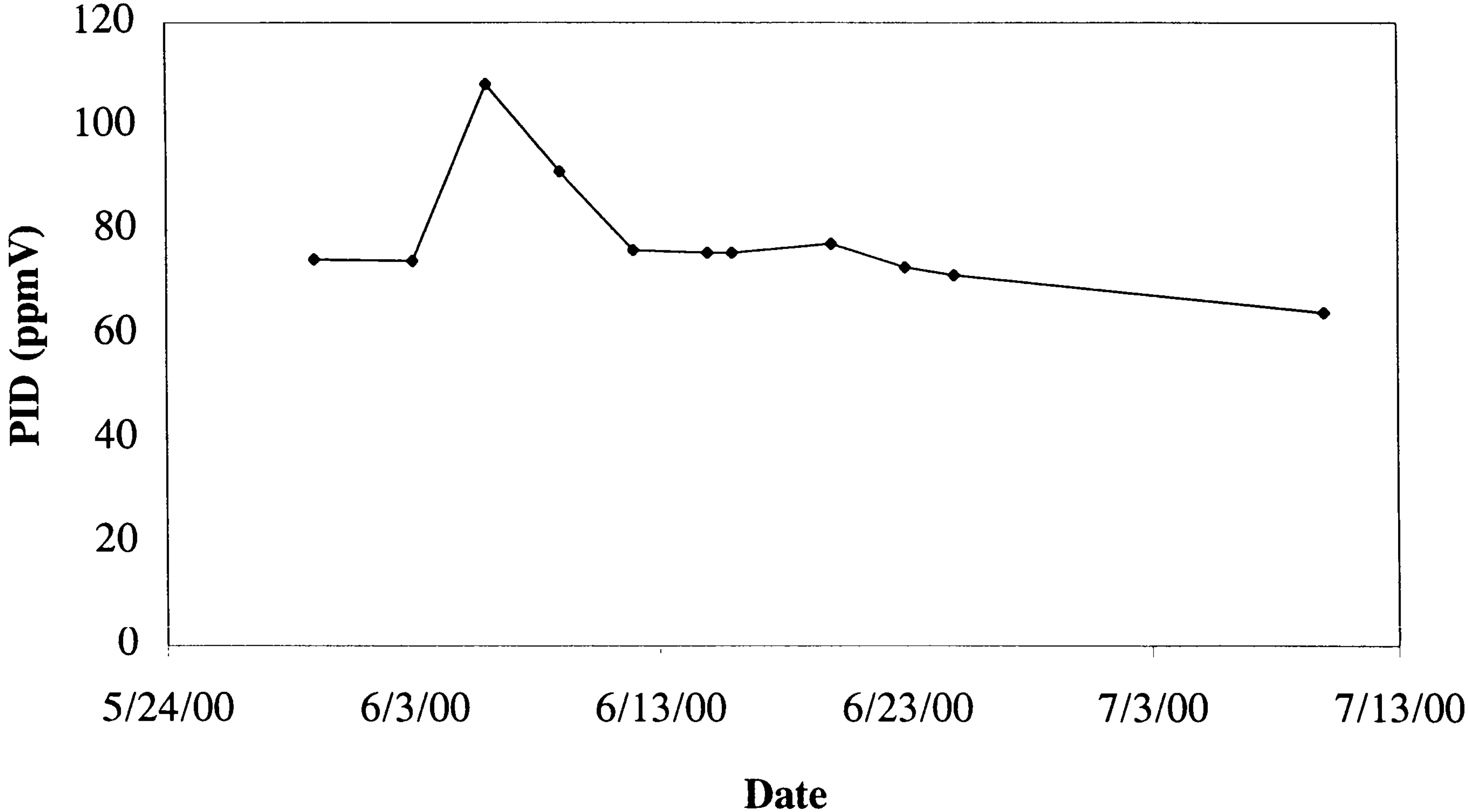
| 025508 | |
| File Name | Figure |
| 25508FIG16 | 16 |

Data from the steady state and transient permeability tests are provided in Appendix B as are the calculations used to determine air permeability for individual well locations within the sand unit. The average air permeability value calculated from the steady state permeability tests was 2,276 darcys. The average air permeability value calculated from the transient permeability tests was 1,430 darcys. While these values are relatively close, both values appear to be high for the nature of the formation tested. As discussed in Appendix B, it is likely that the actual permeability values are lower than this and that the higher values were obtained due to factors such as well loss, barrier boundaries, and leakage of air from the ground surface.

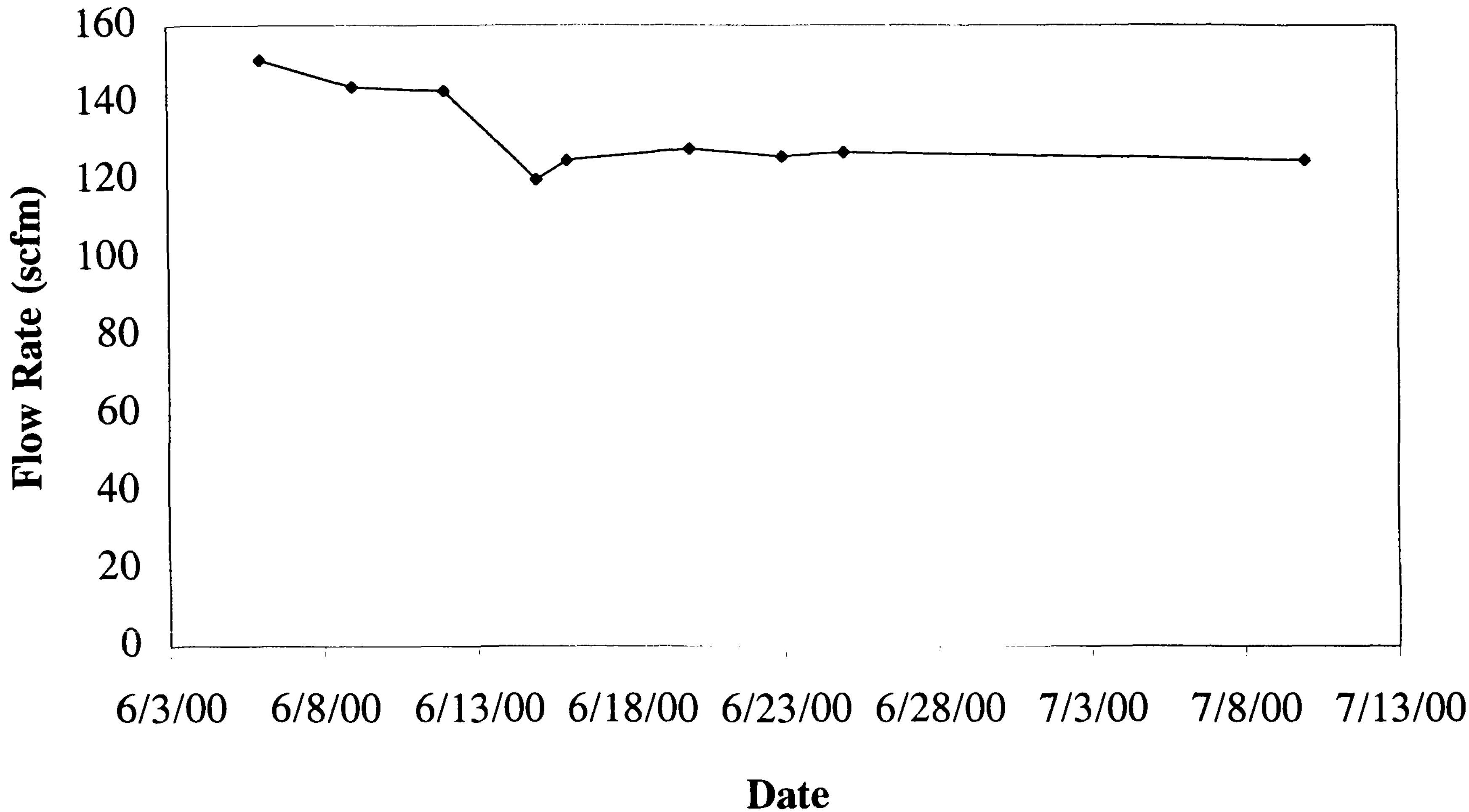
Even if the actual permeability of the sand unit is lower than the values calculated for the above tests, the flow rate and area of vacuum influence indicate that the sand unit is well suited for using SVE to extract contaminants from this unit.

Figure 17 provides the PID data obtained from the SVE unit exhaust over the 40 days that soil gas was extracted from well VP-8. A slight declining trend is evident in the data presented in Figure 17, but the rate of VOC decline is relatively slow over the 40 days of testing. Figure 18 provides the flow rate data over the 40-day period. The flow rate was relatively stable over the test period at just over 120 scfm.

**FIGURE 17**
**SAND UNIT TEST - PID READINGS**



## FIGURE 18
## SAND UNIT TEST - SOIL GAS EXTRACTION RATE



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# Section Five

# 5.0 SUMMARY AND CONCLUSIONS

## 5.1 CLAY-UNIT TESTS

The results of the clay-unit tests indicate that the clay-rich surface soils have sufficient permeability to support soil vapor extraction or air injection to remove residual volatile contaminants in the soils. The tests conducted on VP-10, prior to fracturing indicate that the soil will support a reasonably high air flow rate (approximately 32 scfm) under high vacuum conditions (10 – 12 inches Hg). The steady state permeability calculations for VP-10 prior to fracturing indicate the soil that can marginally support soil vapor extraction without further permeability enhancements.

The tests conducted on VP-10 (pre-fracture) indicated that vacuum influence was observed in all directions that were monitored. The tests also indicated that the vacuum applied to the well was evident in the sand unit below the clay unit. Wells that were completed into the upper portion of the sand unit showed response to vacuum applied to VP-10. This could indicate that natural soil fractures or sand seams connected the well to the sand unit. Such a connection (or series of connections) would allow the well to show a relatively broad area of influence while the actual flow of air through the clay soil could be almost entirely through the preferential pathways leading to the sand unit.

The post fracture test conducted at VP-10 did not show significant increases in the radius of influence, the flow rate, or the calculated permeability. However, a rainfall event reduced the airflow rate through voids and fractures that terminate at the ground surface. Nearly all fractures created by pneumatic fracturing process end at or near the ground surface.

The flow characteristics of the wells receiving the pneumatic fracturing could not be directly compared to VP-10. The rainfall events and the diameter of the boring prevented a direct comparison. The fractured wells were constructed with a smaller diameter boring. In addition, they were tested during and following several rainfall events.

Although the pneumatic fracturing provide a modest increase in air flow and air permeability, it did not improve the conditions sufficiently to warrant its use at this time. Soil vapor extraction without augmentation appears to be sufficient to address the clay unit in those areas impacted above the soil treatment goals.

Air injection tests were conducted following extraction tests in the clay unit. The results indicated that the amount of air moved through the soil was equal to the amount of air withdrawn during the extraction tests. This was accomplished at a lower air pressure that will require lower power requirements. In addition, air injection allows for improved operation of the system during and following rainfall events. Water collecting in the well sumps and in the systems knockout tanks required increased operation and maintenance during extraction tests. The use of air injection will result in more rapid increases in the pore size and pore distribution within the soils. The result is more rapid desiccation effects when compared to extracted soil gas. Air injection will require a separate system to collect and discharge the soil gas that exits the ground surface.

## 5.2 SAND UNIT TESTS

Based on the vapor extraction tests that were conducted on the sand unit, the application of SVE to the sand unit soils is an effective mechanism for removing volatile organic compounds from these soils. The small diameter wells that were installed for this test appear to be sufficient to provide airflow through the areas that have been targeted for soil remediation.

A low vacuum, moderate flow SVE system should be capable of removing volatile contaminants from the sand unit soils where airflow can be sustained. The vacuum response from the long-term tests in the sand unit indicate that with VP-8 and VP-14 operating together provided vacuum influence throughout the area targeted for soil remediation.

One area appears to be anomalous in the SVE tests conducted in the sand unit. The area beneath the building does not appear to be strongly connected to the sands surrounding either VP-8 or VP-14. The vacuum reaction at VP-14 caused by soil gas extraction from VP-8 is relatively small and suggests that the vacuum is arriving at VP-14 through a circuitous pathway. A connection between the VP-8 area and the VP-14 area through the sand unit would be expected to provide greater vacuum at VP-14 while VP-8 is extracting soil gas.

Boring logs from the area in and around the building indicate that a clay lens may be present beneath the building and near the water table. The lens may restrict the flow of soil gas through the sand unit from north to south beneath the building. The location and size of the clay lens could be determined during the installation of SVE wells in the clay unit.

By extracting soil gas from VP-8 and VP-14, it appears that the sand unit soils can be effectively treated. Such a system would also be effective for capturing off-gas emissions created by an air sparge system, and capturing soil gas that would be released in the subsurface if air injection is utilized for the clay-unit and/or the lower clay lens beneath the building.

If air sparging were implemented in the upper portion of the aquifer, it could provide additional treatment to zones that are impacted with volatile organic compounds to augment the existing pump and treat system.

## 5.3 CONCLUSIONS

Conclusions drawn from the pilot test are:

- The clay unit beneath the site is seven to 12 feet thick where measured in the test area.

- Soil vapor extraction in the clay unit, without pneumatic fracturing, is feasible.
- Pneumatic fracturing resulted in a modest increase in airflow rates over those obtained under natural conditions in the clay unit.
- The test did not provide evidence that pneumatic fracturing will increase the radius of effective influence of the soil vapor extraction system in the clay unit.
- The test did not provide evidence that pneumatic fracturing will quantitatively increase the rate of mass removal from the clay-unit.
- An unsaturated sand unit is present beneath the impacted area of the site and beneath the clay unit.
- Soil vapor extraction is feasible in the sand unit.

6

# Section Six

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# APPENDIX A

## ARS Technologies, Inc., July13, 2000,

**Report of Results, Pneumatic Fracturing and**

**Soil Vapor Extraction Pilot Test,**

**Granville Solvents Project, Granville Solvents Site,**

**Granville, Ohio.**

ARS TECHNOLOGIES, INC.

*BREAKING NEW GROUND IN ENVIRONMENTAL TECHNOLOGY*

# REPORT OF RESULTS

# Pneumatic Fracturing and Soil Vapor Extraction Pilot Test

## Granville Solvents Project

Granville Solvents Site
Granville, Ohio

Submitted to:

Metcalf and Eddy
2800 Corporate Exchange Drive, Suite 250
Columbus, Ohio

July 18, 2000

Prepared by:

ARS Technologies, Inc.
271 Cleveland Avenue
Highland Park, New Jersey 08904

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# APPENDICES

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# ACRONYMS

| | |
|---|---|
| AFCEE | Air Force Center for Environmental Excellence |
| AOC | Administrative Order of Consent |
| bgs | Below Ground Surface |
| CVOC | Chlorinated Volatile Organic Compound |
| GSS | Granville Solvents Site |
| ND | Not Detectable |
| PF | Pneumatic Fracturing |
| PID | Photo-Ionization Detector |
| ppm | Parts Per Million |
| ppmv | Parts Per Million by Volume |
| PRP | Potentially Responsible Parties |
| SCFM | Standard Cubic Feet per Minute |
| SVE | Soil Vapor Extraction |
| TCE | Trichloroethene |
| VOC | Volatile Organic Compound |

## 1.0 INTRODUCTION

This report addresses the pneumatic fracturing and soil vapor extraction pilot test activities that were conducted at the Granville Solvents Site in Granville, Ohio from April through June of 2000.

## 2.0 PROJECT BACKGROUND

### 2.1 Introduction

As part of an Administrative Order of Consent (AOC) between the U.S. EPA and a group of potentially responsible parties at the Granville Solvents Site (GSS PRP Group), it was deemed necessary that the soils be treated to levels that would no longer impact the underlying aquifer. From a group of alternatives, Pneumatic Fracturing-enhanced Soil Vapor Extraction (PF-SVE) was selected as a means to assist in the removal of chlorinated and non-chlorinated volatile organic compounds from the soils at the Granville Solvents Site to below soil treatment criteria. Accordingly, a PF-SVE pilot test was proposed whereby it would be applied in a known contaminated area within the unsaturated zone at the Granville Solvents Site.

The preliminary area that was selected to host the PF-SVE activities was agreed upon during a site meeting between ARS and Metcalf and Eddy representatives. This site is located on a portion of land east of the warehouse building which is within the delineated contaminant plume and provides reasonable access for drilling and Pneumatic Fracturing (PF) equipment (Figure 1).

### 2.2 Geology

The Granville Solvents Site is located on alluvial terrace deposits at the northern edge of Raccoon Creek Valley. Based on well logs of the monitoring and production wells, a vertical section of the site could be simplified as a low permeable unit of interbedded fine-grained sand, silt, and clay lenses from ground surface down to the water table, approximately 20 feet below ground surface. Located below this low permeable unit is an aquifer which is comprised of mainly fine to coarse grained sand and silt, interbedded with gravel lenses of various thicknesses. Based on lithologic descriptions of borings drilled during the course of the pilot test, the geology beneath the test area consists of predominantly clay from the surface to a depth of 6 to 10 feet underlain by sand and gravel to below the water table located approximately 20-feet below grade.

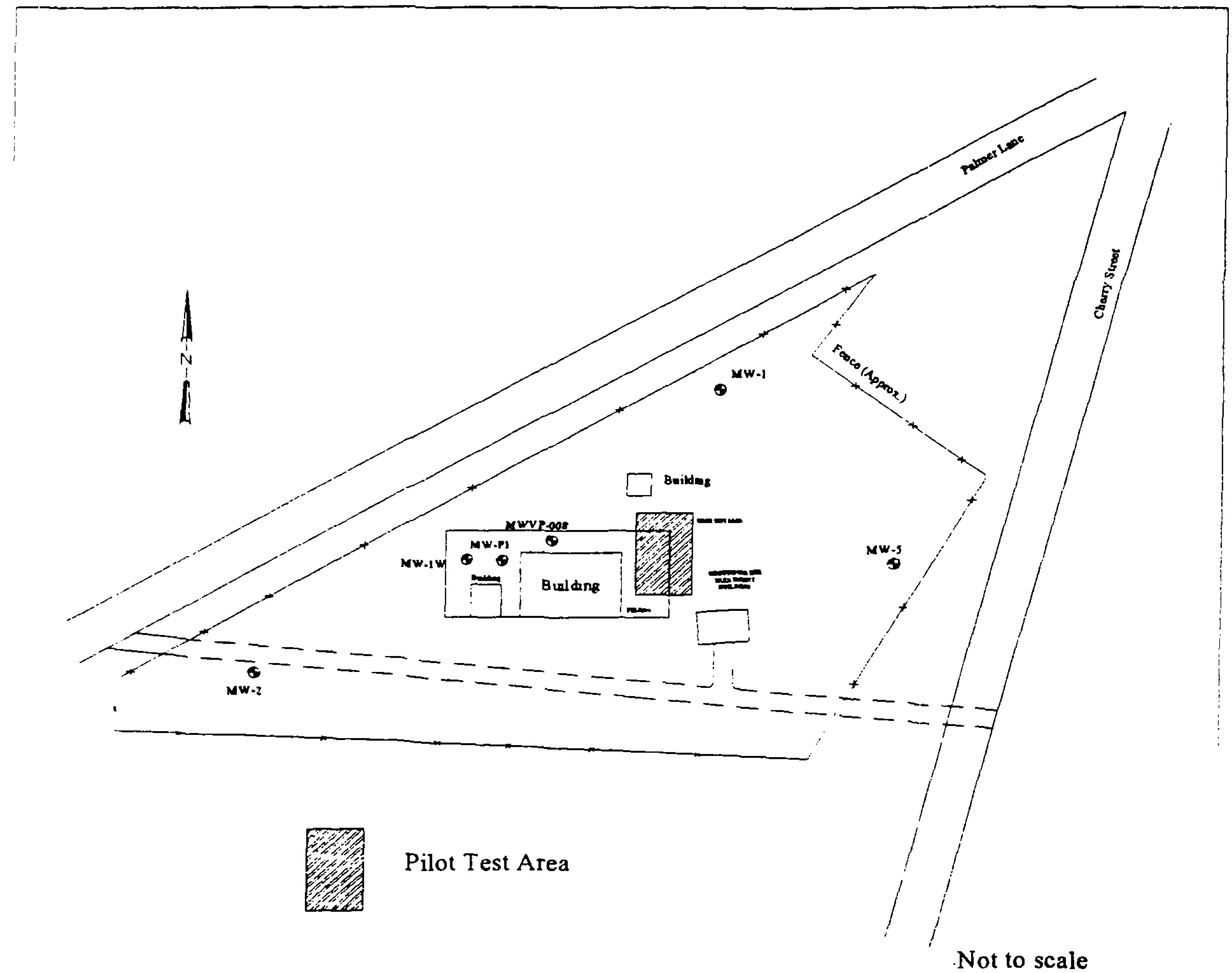



**Figure 1.** Sit map showing pilot test area relative to property boundaries.

## 3.0 TECHNOLOGY BACKGROUND

Pneumatic fracturing is a patented, (US 5,032,042), innovative technology that enhances the *in situ* permeability and hydraulic conductivity of geological formations ranging from sandy silts to tight clays and bedrock. The process may generally be described as the injection of gas into the subsurface at a pressure that exceeds the natural *in situ* stresses, and at flow volumes exceeding the natural permeability of the formation. This causes failure of the medium and creates a fracture network radiating from the injection point. Fracture propagation distances of 20 to 40 feet are typically observed in silt and clay geology. Once established, the newly created fractures allow an increased volume of vapors and/or liquids to flow through the formation. The conventional objectives of Pneumatic Fracturing are to reduce the treatment time by increasing the contaminant mass removal rate, and to extend the effectiveness of available technologies to more difficult geologic conditions. Pneumatic Fracturing has been successfully integrated with other *in situ* treatment technologies such as vapor extraction, bioremediation, and free product recovery. The main goal of applying Pneumatic Fracturing at the Granville Solvents Site is to increase the subsurface air permeability within a targeted area in the unsaturated zone so that SVE is both a feasible and cost effective remedial process for the site.

## 4.0 PILOT TEST STRUCTURE

### 4.1 Project Objective

The pilot test conducted at the Granville Solvents Site was used to evaluate the potential effectiveness of Pneumatic Fracturing (PF) in enhancing Soil Vapor Extraction (SVE) operations. This was accomplished by comparing results from pre- and post fracture SVE tests, and examining the data which were collected during PF injections. More specifically, the following objectives were established for this study:

- Determine the effective vacuum radius of influence before and after fracturing
- Qualitatively determine the fracture pattern
- Determine the extent of fracture propagation and orientation
- Determine the radius of pressure influence during PF injections
- Quantify the increase in the bulk air permeability and mass removal rates provided by Pneumatic Fracturing injections

### 4.2 Project Organization and Scope

ARS Technologies, Inc. (ARS) performed this pilot test under subcontract (M&E JAMIS NUMBER 025508-2000-200) to Metcalf and Eddy, Inc (M&E). Several task groups were performed as part of the pilot test and included drilling and well installation, pre- and post-fracture SVE testing, and Pneumatic Fracturing injections. Post-fracture SVE testing included a 20-day test which was monitored by M&E personnel. Table 1 summarizes the tasks and the date(s) on which they were performed.

**Table 1.** Task Schedule

| Task Description | Date(s) Performed |
|---|---|
| Drilling and Well Installation | April 27 – 29, 2000 |
| Pre- Fracture Soil Vapor Extraction Testing | April 29, 2000 |
| Pneumatic Fracturing Operations | May 1, 2000 |
| Post Fracture Soil Vapor Extraction Testing (short duration tests) | May 1 – 4, 2000 |
| Post Fracture Soil Vapor Extraction Testing (long duration test) | May 4 – 23, 2000 |

### 4.3 Site Layout

The Granville Solvents Site is located at 300 Palmer Lane in Granville, Ohio. The Site, which is on a 1.5-acre triangular shaped lot, is located approximately one-third of a mile southwest of downtown Granville.

Figure 1 shows the location of the pilot test relative to the Granville Solvents site property limits. Included in Figure 1 are the locations of some pre-existing monitoring wells which were measured for vacuum influence during one of the short duration, post fracturing SVE tests. A detailed schematic of the pilot test area is presented in Figure 2 showing the locations of the fracture and monitoring wells used during testing.

## 5.0 WELL INSTALLATION

For application of the PF technology, the installation of two (2) fracture wells was required. To evaluate the influence of fracturing upon SVE processes, the original work plan proposed the installation of seven (7) monitoring wells at various distances surrounding the PF wells, all screened from 5 to 15 feet bgs.

Operating under a subcontract to Metcalf and Eddy, Wright Drilling Co. from Mount Sterling, Ohio installed the fracture and monitoring wells using a hollow stem auger rig following the installation specifications outlined in the pilot test work plan. This included the recovery of continuous split-spoon samples from all monitoring well locations. These cores were logged and then screened for volatile organic compounds (VOCs) using a photo-ionization detector (PID) which was supplied by ARS. Logging and sampling was performed by personnel from both ARS and M&E. All boring logs are presented in Appendix A.

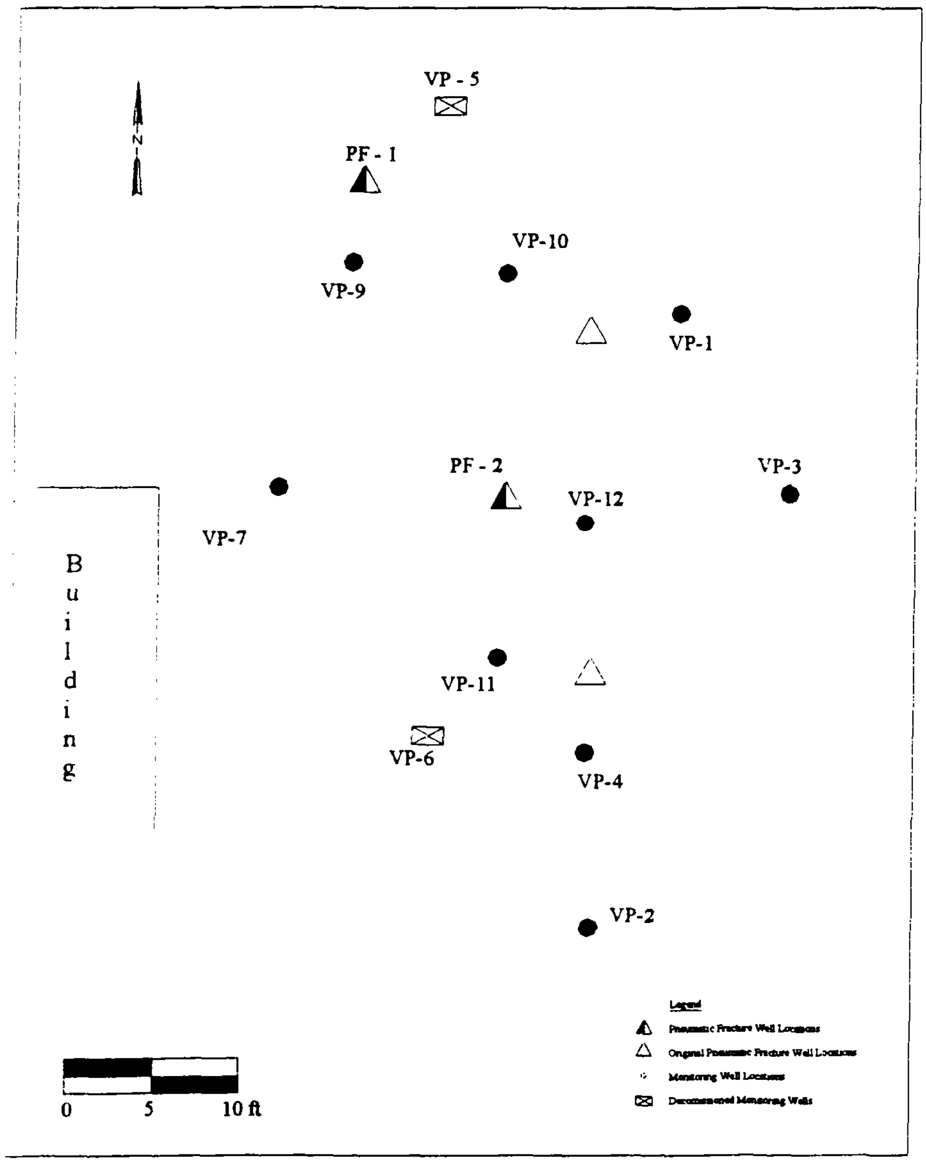



**Figure 2.** Location of wells in pilot test area.

Geologic information obtained from boring logs taken at the Granville Solvents Site prior to this study suggested that clay was present in the area of the pilot test to depths greater than 15 ft bgs. Based on this information, the installation instructions described in the pilot test work plan specified well completion depths to 15 ft bgs. All seven monitoring wells (VP-1 through VP-7) were installed according to this work plan at locations shown in Figure 2. During installation, however, it was discovered that competent clay existed to depths no greater than 10 feet bgs (see boring logs, Appendix A-1). Subsequent site meetings with M&E personnel resulted in changing the locations of wells proposed in the work plan to target the shallow clay layer. This action resulted in the decommissioning of wells VP-5 and VP-6, the addition of wells VP-9, VP-10, VP-11, VP-12, and the installation of wells VP-8 and VP-1W.

Wells VP-8 and VP-1W are located outside the immediate area of the test zone and were used as exploratory boreholes to determine whether the west or north sides of the abandoned warehouse would be more suitable for the pilot study. These boreholes indicated that sand and gravel were present at depths as shallow as 6 and 4 ft bgs, respectively, in those areas. The change to the work plan also resulted in a change to the PF well locations. These new locations were selected to maintain a minimum distance of 15 feet from existing monitoring well locations, while keeping the proposed monitoring well layout as much intact as possible. Figure 2 shows the location of both the original and final PF well locations. The new test area configuration resulted in the placement of PF-1 at the base of a steep grade. Geotechnically, fractures will tend to propagate away from the slope due to lower overburden pressures in that direction. For this reason, no monitoring wells were installed north of PF-1.

The resulting pilot test work area consists of four (4) wells targeting the shallow clay units (< 9ft bgs), and five (5) wells which extend to depths greater than 10 feet bgs where sand and gravel soils are found. Screen intervals for all monitoring wells and completed PF wells are presented in Table 2.

**Table 2.** Depths of well screens for PF and monitoring wells.

| Well | Depth of Screen (ft bgs) |
|---|---|
| VP-1 | 5 – 15 |
| VP-2 | 4 – 14 |
| VP-3 | 4.3 – 14.3 |
| VP-4 | 5 – 15 |
| VP-7 | 6 – 16 |
| VP-8 | 5 – 20 |
| VP-9 | 4 – 8 |
| VP-10 | 4.5 – 7.5 |
| VP-11 | 4 – 8 |
| VP-12 | 4 – 8 |
| VP-13 | 4 – 14 |
| PF-1 | 4 – 7.5 |
| PF-2 | 4 – 7 |

## 6.0 PRE-FRACTURE TESTING PROCEDURES

In order to assist in the evaluation of the PF activities, Soil Vapor Extraction (SVE) tests were conducted prior to, and immediately following fracturing. By comparing the pre- and post fracture data obtained from these tests, the success of Pneumatic Fracturing towards increasing the subsurface bulk air permeability within the target zone at the Granville Solvents Site can be quantified.

### 6.1 Soil Vapor Extraction

Using a skid-mounted vacuum blower unit (consisting of a 10HP positive displacement blower capable of producing a vacuum of up to 13 inches mercury (in. Hg) and extraction flow volumes up to 100 scfm), a pre-fracture SVE test was performed in the test area in well VP-10. Air extraction flow rates were measured using Accutube (Meriam 1.5 inch and 2 inch diameter, Model 10A) flow meters. Dilution flow rates were made using the same Accutube flow meters and an ERDCO (1.5 – 15 SCFM) flow instrument. Vacuum measurements were made using both Dwyer "Magnehelic" brand gauges and a Dwyer digital manometer (Series 475 Mark II). A process schematic of the SVE system used for testing is shown in Figure 3.

During the first 2.75 hours of the test, a source vacuum of 10 in.Hg was applied to the formation. This vacuum was then increased to 12.5 in. Hg for the remaining 2.5 hours. During this test, vacuum influence was monitored at the surrounding network of monitoring wells and the adjacent PF wells. The results of this test are presented and discussed in Section 9.2.1.

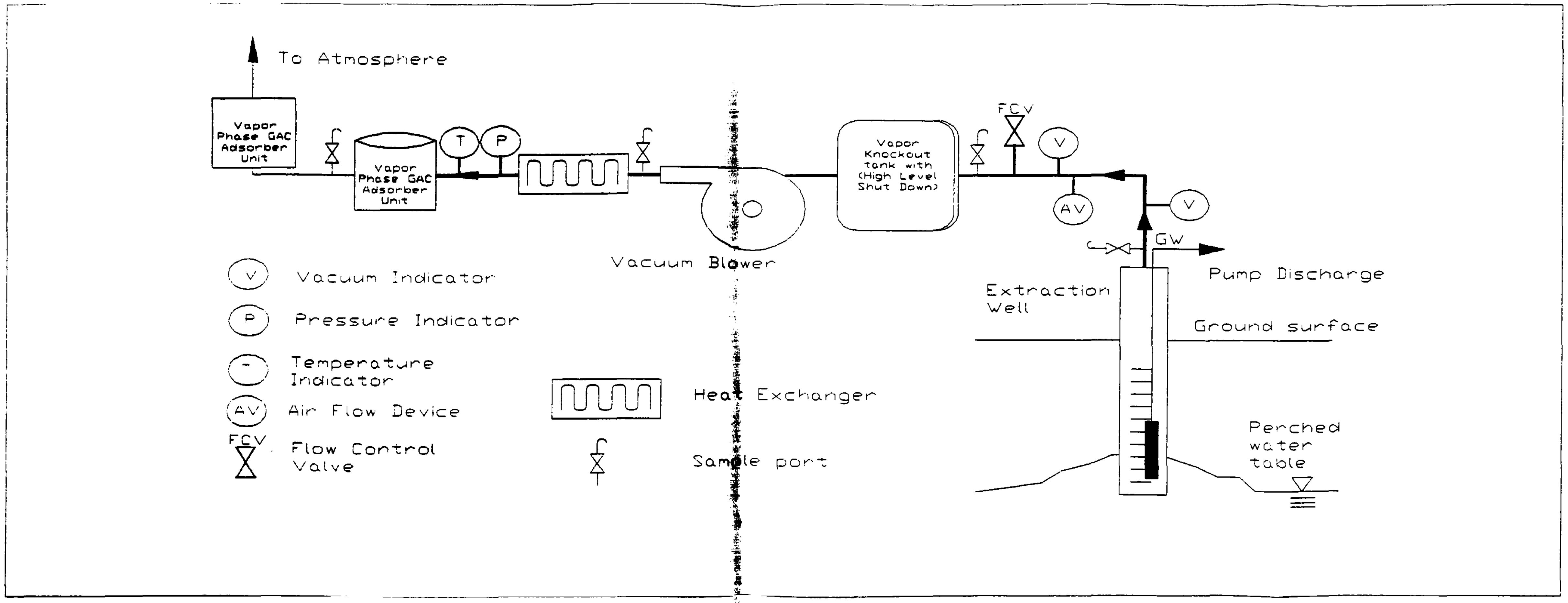



**Figure 3.** Process Schematic for pilot test equipment.

# 7.0 PNEUMATIC FRACTURING OPERATIONS

## 7.1 Pneumatic Fracturing Procedures

Pneumatic Fracturing operations were performed on PF-1 and PF-2 on May 1, 2000. A single injection was applied in each well respectively. Each fracture event consisted of a 15-second injection interval and encumbered a discrete 30-inch linear interval within the borehole from 3.3 to 5.8 ft (PF-2) and 3.7 to 6.2 ft (PF-1). The intervals were sealed using pneumatic packers which were inflated above and below the target zone.

During each injection, data parameters including pneumatic pressure influence at surrounding monitoring points, ground surface heave measurements and visual field observations were made and recorded. Additionally, the pressure in the injection interval was logged electronically using a pressure transducer and datalogger system for later analysis and evaluation. A mechanical gauge with a drag arm, located at the well head also recorded the fracture initiation pressure.

### *7.1.1 Fracture Initiation and Maintenance Pressures*

During each injection, a pressure transducer was located in-line with the high-pressure air supply conduit leading to the down-well fracturing tool. This transducer measured pressure within the supply line every second during the injection. Critical data obtained from the pressure transducer includes the fracture initiation pressure and the fracture maintenance pressure. The fracture initiation pressure represents the pressure at which the formation yields (or fractures). This variable is also recorded by a mechanical gauge with a dragarm that is installed at the wellhead and acts as a backup in case the pressure transducer fails to record during injections. The fracture maintenance pressure represents the pressure required to overcome overburden stress and dilate induced fractures. The graphical representation of this data plotted over time provides insight on the *in situ* stresses of the formation as well as a confirmation that fracturing occurred.

### *7.1.2 Pressure Influence at Adjacent Wells*

During pneumatic injections, pressure gauges were installed at each of the monitoring wells surrounding the injection point, as well as the other PF well. By monitoring the pressure influence in this manner, information about the horizontal and vertical orientation of fractures, extent of the fracture network overlap between the two PF wells, and the understanding of pressure influence within the formation can be attained. In addition to quantifying the performance of Pneumatic Fracturing, the understanding of pressure influence within the formation can be attained. Each gauge is equipped with a drag arm indicator that detects the maximum pneumatic pressure at that well during the injections. This data is used in quantifying the degree and orientation of fracture propagation and connectivity with surrounding wells.

*7.1.3 Ground Surface Heave Monitoring*

Ground surface heave measurements were taken during each injection using surveying transits in conjunction with heave rods. The heave rods were placed adjacent to the PF well being fractured, and also 11 feet from the fracture well. During each pneumatic injection, the rods were monitored with the survey transit to determine the maximum amount of upward motion (surface heave), and the post injection resting position, or permanent displacement, of the ground surface (residual heave). For most applications, ground surface heave monitoring data normally serves as secondary data to quantify fracture propagation.

## 8.0 POST FRACTURE TESTING PROCEDURES

Following Pneumatic Fracturing activities, a series of SVE tests were conducted to assess both short and long term effects fracturing had on formation permeability.

### 8.1 Soil Vapor Extraction

A total of seven (7) post fracture SVE tests were performed in the target zone using wells VP-10, VP-11, VP-8, PF-1 and PF-2 respectively.

The first test was performed in well VP-10 and was conducted in a similar manner as in pre-fracture testing. A vacuum of 10 in. Hg was applied for 2.5 hours and then increased to 12.5 in. Hg for the remaining 2.25 hours of the test. Throughout the test, vacuum influence was monitored in all surrounding monitoring and PF wells.

Subsequent testing was performed in wells PF-1 and PF-2 . Both tests were initiated with an induced vacuum of 10 in. Hg. At well PF-1, 10 in. Hg was applied for 2.8 hours and then increased to 11 in. Hg for 3 hours. The SVE test in well PF-2 was run overnight but also began with an induced vacuum of 10 in. Hg. This vacuum was maintained for 5 hours and then increased to 11.5 in. Hg for the remaining 16.75 hours.

During the pre-fracture testing and during the first three post-fracture tests, no vacuum influence was observed in VP-11. To determine if any connection could be made, a vacuum of 10 in. Hg was applied at well VP-11 for 2 hours and vacuum influence was recorded from all other monitoring wells.

Well VP-8 was installed as a exploratory tool to determine the geology on the north side of the warehouse building. This well was completed with a screened interval from 5 ft to 20 ft bgs. Two tests were performed in this well to observe response in the formation from testing the lower, more permeable units. During the first test, a vacuum of 7 –10 inches of water column was applied to the wellhead for a duration of 15 hours to observe the rate and magnitude of vacuum influence around the site. The second test was conducted over 1.25 hours and involved increasing the flow rate from the formation in three steps. Reaction of the formation was monitored by progressively increasing the vacuum applied to the wellhead from 1.6 to 8.6 inches of water column.

The final SVE test involved extracting air simultaneously from both wells PF-1 and PF-2. A vacuum of 10 in. Hg was applied to the formation and was monitored for 20 days by M&E personnel to determine long term response of the system.

During all of these SVE tests, extraction and dilution flow rates were made using Accutube flow meters. In addition, concentrations of volatile organic compounds were measured using a PID instrument to allow for the calculation of mass removal rates.

## 9.0 PROJECT RESULTS

### 9.1 Geology

During the installation of all monitoring wells, continuous split-spoon samples were taken and logged by both Metcalf and Eddy and ARS personnel. Contrary to original speculation, competent clay was not found continuously to depths greater than 9 feet below ground surface. Gravel and sand are generally found starting at 9 to 10 feet below ground surface within the test site and become shallower towards the west. The gravel is poorly sorted and sub-angular. At surface, the till is weathered to depths of approximately 2 ft bgs, consisting of small amounts of sand and silt. Beneath the weathered zone is a reddish brown silty clay with small seams of sand and gravel. The clay is non-plastic, brittle, with a silt content of approximately 20 percent.

### 9.2 Pre-Fracture Testing

#### *9.2.1 Soil Vapor Extraction*

Pre-fracture SVE testing was conducted on monitoring well VP-10 on April 29, 2000. A vacuum of 10 in. Hg was applied to the formation for 2.75 hours and then increased to 12.5 in. Hg for an additional 2.5 hours. All monitoring wells were measured throughout the test for vacuum influence using a digital manometer (Dwyer Series 475 Mark II). All data collected is presented in Appendix B.

During the test, vapor extraction flow rates were monitored using a 1.5-inch and 2-inch diameter Accutube flow meters which were placed in-line with the extraction hose. By measuring the pressure differential across the Accutube using Magnehelic brand pressure gauges, the flow could be calculated using empirical equations supplied by the manufacturer. 1.5-inch and 2-inch diameter Accutube flow meters were also used to determine the flow rate entering the dilution valve. This valve is used to control the amount of applied vacuum in the extraction well by allowing passive air to enter the blower unit. An ERDCO flow meter (1.5 – 15 SCFM) was used to measure flow entering through the relief valve. This valve is a safety feature and prevents the blower unit from generating too high of a vacuum and potentially overheating.

At a vacuum of 10 in. Hg, the formation produced an average flow of approximately 32 SCFM, as calculated using the Accutube flow equations. After 30 minutes from the start of the test, flow rates appeared to rise substantially. With subsequent testing however, it was discovered that a coupling on the Accutube meter was leaking which attributed to the increase in apparent flow rates. This results in a loss of flow data from 0.5 to 2.3 hours into the test. Passive air flow rates remained relatively small (<23 SCFM) during the initial stages of testing and leveled off at approximately 44 SCFM one hour into the test. Based on flow measurements taken before and after the period when the Accutube valve was leaking and based on dilution valve flow rates during the period, it was conducted that the flow rate remained within the range of 27 to 33 SCFM.

After 2.75 hours, the vacuum was increased to 12.5 in. Hg. Flow rates from the formation averaged 25 SCFM but rose to 31 SCFM after 5 hours had elapsed. Passive air flow rates from the dilution and relief valves, remained relatively constant between 53.7 and 55.7 SCFM.

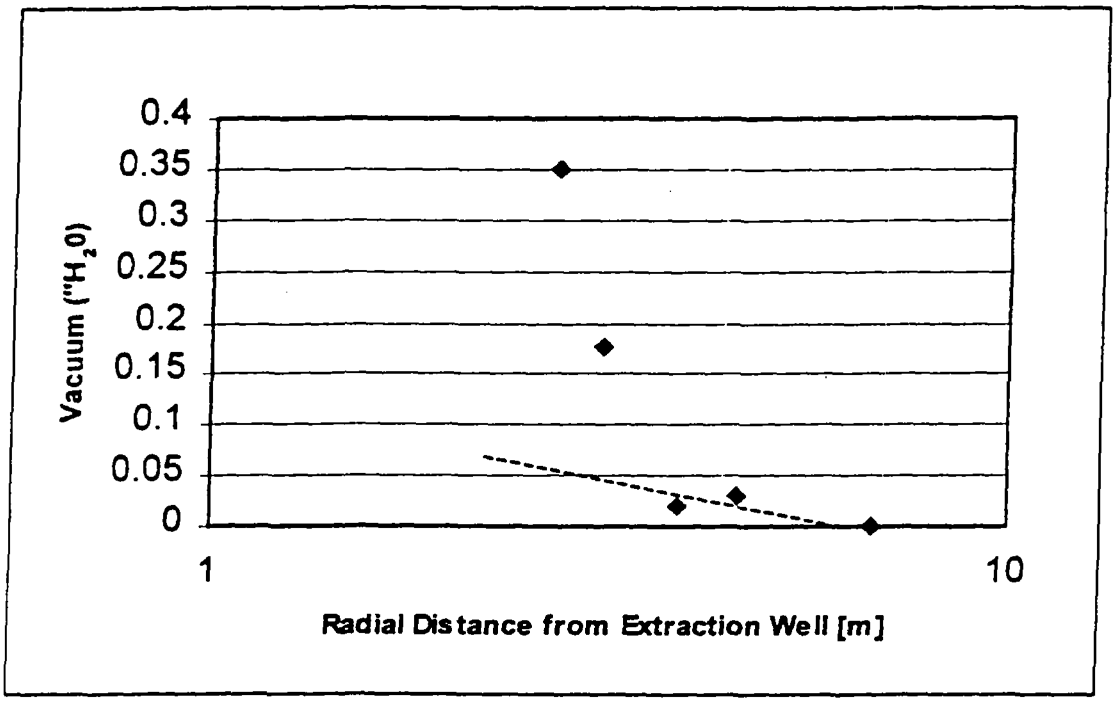
Vacuum influence was observed immediately after the start of the test in the majority of monitoring wells. Measurements as high as 0.225 in. $H_2O$ were made in well VP-9 immediately after the vacuum was induced. Influence was also measured at distances greater than 30 ft (VP-2), resulting in a very large radius of vacuum influence extending outside of the study area. With time, vacuum influence in some well locations rose from non-detect levels to 0.03 in. $H_2O$. In general, response remained relatively constant indicating that steady state conditions were quickly achieved.

The increase in vacuum to 12.5 in. Hg produced an immediate increase in vacuum influence in monitoring wells within 20 feet of the extraction well. After 2 hours, all monitoring wells experienced an increase in vacuum with a maximum measured increase of 0.09 in. $H_20$ (well VP-9).

After 5.25 hours, the vacuum was reduced to 10 in. Hg and the area surrounding the extraction well was sprayed with water to observe the effects water infiltration may have on extraction flow rates. Results show that flow rates began to decline, and after 20 minutes, had fallen more than 10 SCFM.

Assuming that steady state conditions were achieved at later times for each applied vacuum, and assuming an outer boundary condition of 0.01 inches of water column, the maximum radius of vacuum influence and the bulk air permeability of the formation were calculated. The boundary condition of 0.01 inches of water column was selected because it is within the accuracy of the gauges used to measure vacuum influence. To estimate the maximum radius of vacuum influence, the vacuum reading at each monitoring point from the shallow zones of the formation was plotted against the log of its radial distance from VP-10, and the linear section extrapolated to zero vacuum (Figure 4).

**Figure 4.** Vacuum versus radial distance from extraction well.




Based on AFCEE test protocols, the following equation was used to calculate the bulk air permeability under vacuum conditions for the formation within the pilot test area:

$$k = \frac{Q\mu \ln (R_w/R_I)}{H\pi P_w[1-(P_{atm}/P_w)^2]}$$ where;

| | | |
|---|---|---|
| k | = | soil gas permeability ($cm^2$) |
| $\mu$ | = | viscocity of air ($1.8 \times 10^{-4}$ poise at 18°C) |
| Q | = | volumetric flow rate from the vent well ($cm^3/s$) |
| $P_{atm}$ | = | ambient pressure (at sea level $1.013 \times 10^6$ g/cm-$s^2$) |
| $R_w$ | = | radius of extraction well (cm) |
| H | = | screen thickness (cm) |

$R_I$ = maximum radius of vacuum influence at steady state (cm)
$P_w$ = absolute pressure at the extraction well ($g/cm\text{-}s^2$)

This formula was derived for a homogeneous medium which is not necessarily the case in a clayey till as found at the Granville Solvents Site. For calculation purposes the soil was ~~be~~ assumed homogenous and a value of 19.7 ft (as extrapolated from Figure 4), was used as the radius of influence. This is a conservative estimate using only wells that are screened in the upper clay zone.

The pre-fracture bulk air permeability value, determined from the vacuum data when the formation was subjected to 12.5 in. Hg, was $2.79 \times 10^{-8}$ $cm^2$. When the formation was subjected to a vacuum of 10 in. Hg, an effective radius of influence of 18.05 ft was estimated using the same procedure as above, and results in a bulk air permeability of $3.82 \times 10^{-8}$ $cm^2$. These values compare favorably and seem reasonable for a shallow till deposit with significant percentages of sand and gravel content.

Vapor concentrations were monitored throughout the test by sampling the effluent of the blower unit using a PID instrument (HNU System Inc., Photonizer/Datalogger, model DL-101) supplied by ARS. At an induced vacuum of 10 in. Hg, concentrations consistently rose over time to levels as high as 29.2 ppmv. At a vacuum of 12.5 in. Hg, the concentrations increased to 38.6 ppmv and rose steadily over the duration of the test, reaching a maximum concentration of 44.4 ppmv. The concentration level decreased to 35 ppmv once the vacuum was reduced back to 10 in. Hg.

Assuming that PCE was the predominant volatile organic compound measured with the PID instrument, mass removal rates were calculated. Given a molecular weight of 166g/mol and averaging the flow rates and PID measurements over the first 2.3 hours of the test when a 10 inch Hg vacuum was applied, a mass removal rate of 0.53 Kg/day was calculated. Using the same calculation method, an increase in mass removal rate to 0.95 Kg/day was observed during the time that the formation was subjected to a 12.5 in. Hg vacuum. Mass removal rates were calculated by taking into account the passive dilution air that was entering the blower unit through the dilution and relief valves.

## 9.3 Pneumatic Fracturing

### *9.3.1 Data and Results*

PF injections were performed in wells PF-1 and PF-2 on May 1, 2000. Table 3 provides data collected during each injection including the injection interval, injection duration, injection set pressure, fracture initiation pressure, and surface heave data. Each of the parameters monitored during fracturing serves to quantify the effectiveness of the pneumatic injections.

**Table 3.** Data from Pneumatic Fracturing Process

| Injection | Well | Depth Interval (ft bgs) | Injection Duration (sec) | Injection Set Pressure (psi) | Fracture Initiation Pressure (psi) | Fracture Maintenance Pressure (psi) |
|---|---|---|---|---|---|---|
| 1 | PF-2 | 3.3 – 5.8 | 15 | 250 | 92 | N/A |
| 2 | PF-1 | 3.7 – 6.2 | 15 | 250 | 100 | N/A |

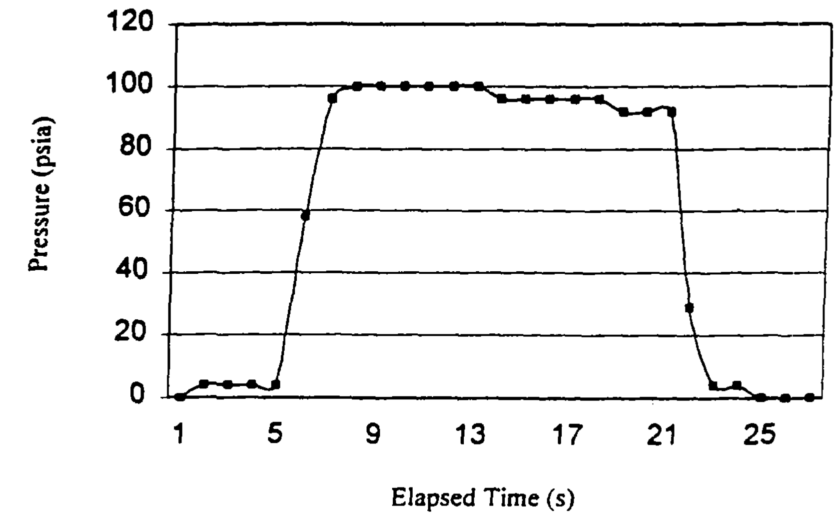
*9.3.2 Analysis and Pressure Transducer Data*

During each injection, the pressures in the injection interval are recorded by a pressure transducer located in-line with the conduit leading to the injection zone. These pressures are transferred to a data logging system which is located in the fracture trailer. During the first injection, a wire was dislodged from this data logger unit resulting in the loss of data during this injection. This problem was corrected and a pressure curve was successfully collected for the second fracture attempt. By analyzing both the magnitude and shape of this curve and comparing it to prior applications in similar geology, an assessment of fracture effectiveness can be made. This information provides two critical measurements; the fracture initiation pressure and the fracture propagation pressure. The fracture initiation pressure is also recorded using a mechanical gauge with a drag arm at the well head. The recorded fracture maintenance pressure is an average over the propagation time.

The time-history curve collected during injection at PF-1 is presented in Figure 5. This curve does not indicate a distinct initiation pressure that is typically seen during fracturing propagation. Large overburden pressures which cause these distinct initiation pressures were not present during injections at the Granville Solvents Site due to the shallow nature of the injection wells.

*Three distinct plateaus are seen in the curve in Figure 4. These plateaus may represent* the fracturing of the clay and subsequent dilation of existing preferential pathways. Near surface, the formation is weathered and may have a higher permeability than at greater depths (>4 ft). The dilation of existing pathways would account for measured surface heave and increases in permeability which are seen in subsequent data sets.

**Figure 5.** Pressure versus history curve recorded during injection at well PF-1




Daylighting was observed approximately 9ft from the well in a north-east direction during injection at PF-2 (The term "daylighting" is referred to fractures which propagate to, and intersect ground surface). These types of fractures are usually identified by soil and debris being expelled from the ground at a concentrated point. If pressurized air moved along an existing pathway to surface, it could be mistaken for a daylighting fracture. No daylighting was observed during injection at PF-1 and is confirmed by the lack of an abrupt pressure drop along the curve in Figure 5. When daylighting occurs, high pressurized air within the well will preferentially flow towards atmospheric conditions at the surface. This causes a significant drop in the pressure within the well, and is subsequently recorded by the pressure transducer.

### *9.3.3 Analysis of Pressure Influence*

During each injection, pressure gauges were installed at each of the monitoring points and the adjacent PF well. The pressure influence readings during the fracturing are presented in Table 4.

**Table 4.** Pressure influence during pneumatic fracturing operations.

| | Pressure Influence during Injections (psi) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection | PF-1 | PF-2 | VP-1 | VP-2 | VP-3 | VP-4 | VP-5 | VP-6 | VP-7 | VP-9 | VP-10 | VP-11 | VP-12 |
| 1 | ND | --- | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.25 |
| 2 | --- | 0.1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

Note: Injections correspond to depth intervals in Table 3
ND - Not Detected

Minimal pressure influence was observed during either injection at the Granville test site. During the first injection, conducted in well PF-2, a pressure of 0.25 psi was observed in well VP-12. No other wells indicated pressure influence. The lack of response is due to the shallow depth intervals that were targeted. From prior studies of pneumatic and hydraulic fracturing, fracture propagation will naturally rise with distance from the injection point. This was evident at the site by the daylighting of a possible fracture at approximately 9 ft from the injection interval in a north-easterly direction. VP-12 is the only well in the site configuration that is located within a 10-foot radius and therefore is the only well showing any pressure response.

In addition, all monitoring wells installed at the test site were completed with the screened section located at least 4 feet below ground surface. The upper 3.5 to 4 ft section of the well was cement grouted to secure the wells. Since the fracturing interval in well PF-2 was from 3.3 to 5.8 feet bgs, any fractures which may have propagated further than 9 feet at shallow depths, would not have influenced a monitoring well at that location since they would be located above the screened interval.

These same arguments can be made for the second injection that occurred in well PF-1. During this injection, a pressure response of 0.1 psi was observed in PF-2 that may indicate that fracture connection between the two injection points had occurred.

### *9.3.4 Discussion of Surface Heave Data*

Surface heave monitoring serves to provide supplemental evidence to support fracture propagation during pneumatic injections and after injections are terminated. In both cases, ground surface heave was measured directly adjacent to the well being fractured, as well as 11 feet radial distance. Heave adjacent to PF wells 1 and 2 during injections were 0.065 ft and 0.08 ft respectively. At a distance of 11 ft during injections, heave of 0.02 ft was measured for well PF-1 and 0.03 ft for PF-2.

Residual heave was also measured adjacent to the fracture wells during both injections and values of 0.02 ft and 0.03 ft recorded at wells PF-1 and PF-2, respectively. No residual heave was measured at 11 ft radial distance from the well. This data is summarized in Table 5.

**Table 5.** Ground surface heave measurements during Pneumatic Fracturing injections

| Injection | Maximum Surface Heave (feet) | | Residual Surface Heave (feet) | |
|---|---|---|---|---|
| | 1 foot from wellhead | 11 feet from wellhead | 1 foot from wellhead | 11 feet from wellhead |
| 1 | 0.08 | 0.005 | 0.03 | 0 |
| 2 | 0.065 | 0.001 | 0.02 | 0 |

ND – not detected

The residual heave measured adjacent to the injection wells PF-1 and PF-2 indicates that fracturing or dilation of existing pathways had taken place. The residual heave data from distances of 11 feet from the injection point, combined with daylighting observed during the first injection and the lack of pressure influence observed in the monitoring wells, suggests that the fractures did not propagate further than 10 feet from the injection points.

### 9.4 Post Fracture Testing

#### *9.4.1 Soil Vapor Extraction*

The following sections discuss the post fracture SVE tests conducted at the Granville Solvents test site. All data sheets are located in Appendix B.

The calculated values for bulk air permeability and mass removal rates for both the pre- and post-fracture SVE tests conducted during the pilot test at the Granville Solvents Site are summarized in Table 6. Subsequent sections of this report discuss each post-fracture SVE test in more detail.

**Table 6.** Bulk air permeability and mass removal rates for all pre- and post-fracture SVE tests conducted at the Granville Solvents Site.

| Extraction Well | Applied Vacuum [inches Hg] | Bulk Air Permeability [cm$^2$] | Mass Removal Kg/day |
|---|---|---|---|
| VP-10 (pre-fracture) | 10 | 3.82 x 10E-8 | 0.499 |
| | 12.5 | 2.79 x 10E-8 | 0.899 |
| VP-10 (post-fracture) | 10 | 4.42 x 10E-8 | 0.250 |
| | 12 | 3.22 x 10E-8 | 0.192 |
| PF-1 (post-fracture) | 10 | 5.4 x 10E-8 | 0.037 |
| | 11 | 5.08 x 10E-8 | 0.028 |
| PF-2 (post-fracture) | 10 | 4.09 x 10E-8 | 0.558 |
| | 11.5 | 5.05 x 10E-8 | 0.822 |
| VP-8 (post-fracture) | 0.67 | n/a | 1.92 |
| PF-1 & PF-2 (post-fracture) | 10 | 1.27 x 10E-7* | 0.473 |
| PF-1 & PF-2 (post-fracture) | 10 | 1.35 x 10E-7** | 0.473 |

* effective radius of vacuum influence calculated using PF-1 and closest monitoring wells

** effective radius of vacuum influence calculated using PF-2 and closest monitoring wells

*9.4.1.1 Well VP-10*

The first post fracture SVE test was conducted in well VP-10 in a similar manner as the pre-fracture test. A vacuum of 10 in. Hg was maintained on the formation for 2.5 hours and then increased to 12.5 in. Hg until 4.75 hours had elapsed.

Pre-test measurements in a majority of the surrounding monitoring wells indicated a slight pressure anomaly, which may be due to trapped gases created by the fracturing process. Once the vacuum was initiated, all wells except for well VP-11 and VP-12 experienced vacuum influence. The magnitude of influence was as much as 0.3 in. $H_20$ in well PF-1. This is an improvement to pre-fracture conditions and suggests that fracturing had increased the connectivity with PF-1. After 2 hours, monitoring wells within the vicinity of the extraction point indicated an increased vacuum influence up to 0.08 in. $H_20$ (well VP-9).

Extraction flow rates measured during the first two hours of the test indicated an average increase from approximately 32 SCFM during pre-fracture conditions to 37 SCFM during post fracture testing.

After 2.5 hours the induced vacuum was increased to 12.5 in. Hg. Measurements made in surrounding monitoring well locations immediately after the vacuum was increased, indicate a similar response to pre-fracture conditions. Extraction flow rates remained relatively constant at the increased vacuum of 12.5 in. Hg, with a calculated flow of approximately 37.5 SCFM.

Using the same methods as outlined in Section 9.2, values of effective radius of influence and bulk air permeability were calculated. An effective radius of influence for induced vacuums of 10 and 12.5 in. Hg were extrapolated to 18 and 16.4-feet, respectively. Using the equation in Section 9.2, a bulk air permeability value of 4.42 x $10^{-8}$ $cm^2$ was calculated for the formation when subjected to a vacuum of 10 in. Hg. When the applied vacuum was increased to 12.5 in. Hg, a value of 3.22 x $10^{-8}$ $cm^2$ for bulk air permeability was calculated. This indicates that only a minor increase in bulk air permeability occurred at location VP-10 from pneumatic fracturing activities. However, a major rainfall event occurred near the start of the post-fracture test of VP-10. It is likely that the rainfall filled fracture voids and prevented the accurate measurement of post-fracture permeability.

Mass removal rates, calculated in a manner similar to pre-fracture testing, suggest that water infiltration was affecting the test. Under a 10 inch Hg vacuum, mass removal rates dropped from 0.42 Kg/day in pre-fracture conditions to 0.21 Kg/day during post-fracture testing. When the vacuum was increased to a 12 in. Hg vacuum during the post-fracture test, the rate of mass removal dropped even further to 0.16 Kg/day. This discrepancy in data is attributed to water infiltration that would effect flow within the formation. Precipitation began at the start of the test and continued throughout its duration.

*9.4.1.2 PF-1*

SVE testing was conducted at PF-1 on May 3, 2000 over a 6-hour period. A vacuum of 10 in. Hg was applied to the formation for 2.8 hours and then increased to 11 in. Hg for another 3 hours. Vacuum influence was seen in all wells within 15 feet of the extraction well with the largest measured influence of 0.25 in. H20 in well VP-9, located 5.25 feet from the extraction well. Vacuum fluctuations were observed in wells VP-2 and VP-4 which are located greater than 35 feet from the extraction well. These fluctuations could be due to the large distances and the sensitivity of the gauges used to measure the low vacuum.

An increase in vacuum to 11 in. Hg resulted in little change to the system. Minimal change occurred in recorded values of vacuum influence except in well VP-9. At this location the vacuum increased from 0.25 in. $H_20$ to 0.33 in. $H_20$.

Extraction flow rates remained constant between 31 and 35 SCFM throughout the test. During a vacuum of 11 in. Hg, the extraction flow rate showed less fluctuation and ranged between 34 and 35 SCFM.

An "effective" radius of influence of 16.4 ft and 21.1 ft was extrapolated for the formation at vacuums of 10 and 11.5 in. Hg, respectively. Using these distances, bulk air permeability values of 5.4 x $10^{-8}$ $cm^2$ and 5.08 x $10^{-8}$ $cm^2$ are calculated. As in the previous test, the values of mass removal dropped from 0.03 Kg/day to 0.02 Kg/day when the vacuum was increased. This drop however, is attributed to the malfunctioning of the pumps to remove the standing water in the extraction well. At the end of the test, 1.7 feet of water was found in the extraction well.

*9.4.1.3 PF-2*

An SVE test was performed on well PF-2 on May 2, 2000 over a period of 21.75 hours at induced vacuums of 10 and 11.5 in. Hg. Measurements of vacuum influence made immediately after initiating the test indicate response in all wells except for VP-11 and VP-12. Minimal response was measured in PF-1 and subsequently fell to non detectable values after 2.5 hours.

During the intermediate stages of this test, the system was repeatedly shut down to remove standing water from the extraction wells. The pumps that were initially installed were found inadequate for the system design and were ultimately replaced. No significant changes in vacuum influence could be made during this time and extraction flow rates remained relatively constant at 33 SCFM.

After 5 hours, the vacuum was increased to 11.5 in. Hg and the system was monitored for 4 hours. At that time little response could be seen in any monitoring wells while extraction flow rates remained constant at approximately 32 SCFM.

The system remained running overnight at an induced vacuum of 11.5 in. Hg. In the morning, a vacuum of 1.61 in. Hg was measured in well VP-12, a significant increase from non-detectable levels the night before. Little change in vacuum influence was observed in the remaining monitoring wells.

Effective radii of influence of 16.4 ft were estimated for both the 10 and 11.5 inch vacuums. The resulting air bulk permeability values calculated for the 10 inch and 11.5 inch vacuums were $5.05 \times 10^{-8}$ $cm^2$ and $4.09 \times 10^{-8}$ $cm^2$, respectively. These values are in general agreement and attest to the accuracy of the derivation. Mass removal at this location increased from 0.47 to 0.68 Kg/day for the 10 inch and 11.5 inch Hg vacuums, respectively.

*9.4.1.4 VP-11*

Throughout SVE testing, no vacuum response could be measured in VP-11, even when the induced vacuum was located within a 10 foot radial distance. Therefore, a very short SVE test was conducted to determine if any vacuum influence could be achieved. On May 4, 2000, a vacuum of 10 in. Hg was induced for 2 hours at well VP-11 and vacuum influence was monitored at all surrounding monitoring well locations.

During the two hours, no influence was measured within any surrounding well locations, indicating that no connection was achieved. Extraction flow rates remained constant at

30 SCFM with no influence at radial distances of 10 ft, which may indicate that there is short circuiting to surface or that the vertical permeability is much higher than the horizontal permeability. Passive air flow rates as high as 52 SCFM were recorded.

No air bulk permeability or mass removal rates were calculated for this test.

*9.4.1.5 VP-8*

Two SVE tests were conducted at well VP-8. This well is located to the north of the warehouse building, outside of the immediate test area and is screened from 5 to 20 feet bgs, within the lower, more permeable soil.

The first test was conducted on May 4, 2000 and was monitored for 15 hours. The maximum vacuum achieved on well VP-8 was 8.6-inches of water column. Vacuum response was immediately measured in all wells except for VP-11 and PF-2. VP-11 indicated no response while a pressure rise was measured in PF-2.

After 1 hour, vacuum monitoring at pre-existing wells that border the perimeter of the property (MW-2 and MW-5), indicated influence of 0.02 and 0.05 in. $H_20$ respectively. Testing continued until the following morning and was terminated after 15 hours had elapsed. At that time, values of vacuum influence in all wells had risen slightly, with a maximum influence of 0.22 in. $H_2O$ in well VP-007, approximately 35 feet from the extraction well. A vacuum of 0.44 in. $H_20$ was measured at well VP-012, however, this vacuum dropped to zero when opened to atmosphere and could not be verified in subsequent attempts.

Flow rates during this test remained relatively constant around 103 SCFM with no passive air entering the blower system. One hour after terminating the test, all monitoring wells were measured for vacuum. At this time all vacuum influence had dissipated from the formation. The radius of influence based on this test extended beyond the boundaries of the site. No bulk air permeability was calculated.

The second SVE test conducted at well VP-008 was designed as a short "step" test. The vacuum induced on the formation was increased every one half hour beginning at 1.6, 5.5, and 9.5 inches of water column. This resulted in extraction flow rates increasing from 39 SCFM to 82 SCFM to 106 SCFM, respectively.

During each "step", vacuum influence was monitored at wells VP-007, VP-009, P-1, and MW-13. Vacuum influence was observed to increase between both steps with approximately an order of magnitude increase occurring between the first two steps.

No bulk air permeability calculation was made for this test.

*9.4.1.6 PF-1 and PF-2*

Beginning May 4, 2000, a long term SVE test was conducted where air was extracted simultaneously from both wells PF-1 and PF-2. A vacuum of 10 in. Hg was induced on the formation and the system was monitored for 20 days by Metcalf and Eddy personnel.

Using AFCEE test protocols as outlined in Section 9.2, the effective radius of vacuum influence and bulk air permeability were calculated. Since air was extracted from two wells simultaneously, the effective radius of influence could not be calculated using the log radial versus vacuum influence approach as was done previously for one source. Therefore, two effective radial distances were calculated for wells PF-1 and PF-2 independently of one another by assuming that influence measured in a monitoring well was caused by the closest extraction well. The resulting radii of influence were estimated at 24.6 feet for PF-1 and 32.8 feet for PF-2.

The values of bulk air permeability for wells PF-1 and PF-2 using the effective radii of influence above, were $1.27 \times 10^{-7}$ cm$^2$ and $1.35 \times 10^{-7}$ cm$^2$, respectively. Comparing these values with those calculated in pre-fracture testing at well VP-10. the post-fracture permeability is approximately 4 times as large. This suggests that pneumatic fracturing had increased permeability locally in the formation, assuming that steady state conditions were reached in both tests. Some of the increase in permeability observed over the 20 day test may have been caused by a drying of the soils. This drying action would open more pore space and potentially expand the size of existing fractures. A similar increase in permeability might be expected if a non-fractured well head received vapor extraction for 20 days. However, the pre-fracture test was conducted on soils that were already relatively dry. Rainfall events which occurred just after fracturing, probability altered the soil permeability for much of the initial post-fracture testing. The long-term test gave the soils a chance to recover the pre-rainfall permeability.

Averaging the vapor concentrations and the flow rates over the last few days of this test, a mass removal rate of approximately 0.473 Kg/day was calculated. This rate is an increase from 0.192 Kg/day, calculated during the first day of operation and is more representative of steady state conditions.

## 10.0 CONCLUSIONS

The PF-SVE pilot test conducted at the Granville Solvents Site in Granville, Ohio provided several conclusions which are relevant to future impact of the technology for site remediation.

1. Geology: Based on soil logging conducted during well installation, it was found that gravel and sand units were present at the pilot test area as shallow as 9 feet below ground surface and become shallower towards the west.

2. Maintenance Pressure: By examining both the shape and magnitude of the time-history curve from PF-1, important information can be obtained. The stability of the maintenance pressure indicates that fracture propagation remained mainly within the low permeable zones of the formation and did not daylight. The average magnitude of the maintenance pressure (~95 psi) is consistent with other applications within similar geological formations at this depth.

   Initiation Pressure: Fracture initiation pressures for wells PF-1 and PF-2 as measured by mechanical gauges at the well heads, were 92 and 100 psi respectively. The time-history curve for PF-1 does not exhibit a fracture initiation peak and may be attributed to the lack of overburden pressures at shallow depths. A similar type curve would be expected for PF-2.

3. Fracture Propagation (Pressure Influence): Measurable pressure influence was observed at a maximum distance of 10 feet during the first injection (PF-2). During this injection, daylighting was observed at a distance of approximately 9 feet from the injection well. The shallow nature of the injections which tend to propagate outward and upward minimized propagation distances of the fractures. The lack of pressure influence at the adjacent monitoring wells most likely can be attributed to this upward propagation.

   During injection at PF-1, pressure influence of 0.1 psi was measured at PF-2, indicating that connection between the two fracture wells had occurred.

   Fracture Orientation: With the lack of measured pressure influence in surrounding monitoring wells, it is difficult to establish a fracture orientation. However, during injection at PF-2, a single well indicated pressure response in an easterly direction. Daylighting was also observed in this direction suggesting that the fractures propagated towards surface with distance from the injection well towards the east. Surface heave measurements made during injection also indicate that fractures propagated in a southerly direction. The extent of these fractures, however, would have been hindered due to pressure loss caused by the daylighting occurring in the east.

   During the injection at PF-2, the presence of a steep incline to the north would theoretically suggest that any induced fractures would tend to propagate away from the slope. This was confirmed with a small pressure influence in well PF-1 located at a distance of 20 feet. Surface heave data also supports this conclusion.

4. SVE Testing: Direct comparisons between the long term post fracture SVE test and pre-fracture testing is difficult due to different test parameters. No significant bulk air permeability increase could be measured between pre- and post fracture conditions in VP-10. However, if pre-fracture values of bulk air permeability, measured at VP-10

are assumed representative of the entire formation in the test area, then comparison to values calculated during the long term extraction test in PF-1 and PF-2,

suggests an increase in bulk air permeability of approximately half an order of magnitude from 4.88 x $10^{-8}$ $cm^2$ to 1.21 x $10^{-7}$ $cm^2$. These values are calculated under a source vacuum of 10 in. Hg. Since no pre-fracture mass removal rates were calculated in wells PF-1 and PF-2, direct comparison to pre-fracture conditions in well VP-10 are unrealistic. Mass removal rates between pre- and post fracture conditions in well VP-10 show a decrease from 0.42 Kg/day to 0.21 Kg/day. This however, is most likely attributed to water infiltration caused by precipitation

which occurred continuously during the post fracture test. This indicates that at shallow depths, weather conditions may impact this type of remedial strategy. This effect was confirmed by spraying water around extraction well VP-10 during the latter stages of the pre-fracture test which caused extraction flow rates to decrease.

Using the data generated during the pilot test, it is the overall conclusion of this report that the installation of a shallow clay zone SVE system can be effective in treating the clay matrix. This is based on evidence showing an increase in the subsurface bulk air permeability from 4.88 x $10^{-8}$ $cm^2$, measured during pre-fracture conditions in well VP-10, to 1.21 x $10^{-7}$ $cm^2$, measured in wells PF-1 and PF-2 during post fracture testing. In addition, an increase in the effective radius of vacuum influence of 250cm and 500cm in wells PF-1 and PF-2 between pre- and post fracture conditions was observed. Finally, the combined air extraction from wells PF-1 and PF-2 after pneumatic fracturing activities resulted in flow rates as high as 58 SCFM and mass removal rates of 0.4 Kg/day at steady state.

## Appendix A

Soil Boring Logs

ARS Technologies

# SOIL BORING LOGS



| | | | |
|---|---|---|---|
| **CLIENT** | METCALF & EDDY | **SITE** | GRANVILLE SOLVENTS |
| **JOB NO.** | 20-42 | **DATE DRILLED** | APRIL 27, 2000 |
| **DRILLING Co.** | Wright | **DRILLER** | Densil/ Darryl |
| **BORING No.** | VP - 7 | **DRILLING METHOD** | '4 AUGER (HAS) |
| **GROUND ELEVATION** | | **WATER TABLE DEPTH** | |
| **FIELD SCIENTIST/ ENGINEER** | Mark Andrew (M&E)<br>Steve Markesic (ARS) | **ORGANIC VAPOR INSTRUMENT USED** | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| 0 - 2' | SS' | 4 6<br>5 6 | 1.5'<br>70% | | 4" top soil 20% silt<br>silty clay, brown, firm 10% sand<br>15% gravel | 1.4, 1.8<br>1.9 |
| 2 - 4' | SS' | 5 7<br>9 12 | 2'<br>100% | | Very competent silty brown clay<br>few visible fractures, low plasticity<br>20% silt, 5% gravel/pebbles, 10% sand | 1.2, 1.2<br>1.5, 8.9 |
| 4 - 6' | SS | 4 9<br>12 14 | 2'<br>100% | | As above but slightly wetter with larger<br>sized pebbles [up to 10mm] | 2.9, 6.2<br>15.4, 31.8 |
| 6 - 8' | SS | 5 7<br>14 14 | 2'<br>100% | | Silty clay<br>gravel layer @ 7.5'<br>lighter in color than above<br>10% gravel, 20% silt, 10%sand | 6.1, 12.0<br>9.2, 6.3 |
| 8 - 10' | SS | 4 4<br>4 5 | 1.5'<br>75% | | very wet<br>gravely layer with high sand/silt content<br>large pebbles present >2cm<br>reddish brown near top turning to dark brown<br>@ bottom of sample<br>20% gravel, 20% silt, 15% sand | 6.2, 14.8<br>1.8 |
| 10 - 12' | SS | 5 10<br>6 7 | 2" < 5% | | same as above | N/A |
| 12 - 14' | SS' | 5 11<br>14 16 | 2" < 5% | | as above | 1.1<br>2.8, 8.0 |
| 14 - 16' | SS' | 14 11<br>11 11 | 1' 50% | | gravel layer<br>pebbles from 1mm to 3mm<br>20% sand, 20% silt | 5.1 |
| | | | | | Screen 16 - 6' bgs.<br>Sand 16 - 5.5' bgs. | |

ARS Technologies

SOIL BORING LOGS



| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | April 27, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/Darryl |
| BORING No. | VP-1 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| | 3" | | | | Top soil profile to silty clay | 0.9, 0.9 |
| 0 - 2<br>(12:55) | SS | 3 7<br>7 8 | 1.5 75% | | weathered silty clay (cl), trace cobble & sand<br>20% silt, dark reddish brown | 1.0 |
| 2 - 4<br>(13:00) | SS | 6 9<br>10 13 | 2.0 100 | | Silty clay (cl) as above | 18.8,<br>.9 - 1 |
| 4 - 6<br>(13:03) | SS | 5 8<br>14 16 | 2.0 100 | | Silty clay (cl), dark brown<br>Firm, dense, moist, non plastic<br>10% small gravel, 20% sand, 20% silt | 1.0, 1.5<br>1.0 |
| 6 - 8<br>(13:08) | SS | 5 8<br>35 16 | 2.0 100 | | High count shattered cobble<br>silt clay as above (4 - 6) | 1.6, 1.4<br>1.4 |
| 8 - 10<br>(13:15) | SS | 5 7<br>8 8 | 1.5 75% | | Sand zone (sm) 8" coarse - poorly sorted<br>some coarse gravel. 20% silt<br>silty clay (cl), 50% of sample<br>as above | 11, 1.6<br>1.4 |
| 10 - 12<br>(13:20) | SS | 11 12<br>12 18 | 1.5 75% | | Silty clay with 40% gravel, 20% sand<br>20% silt, friable dry | 4, - 17, - 10 |
| 12 - 14<br>(13:26) | SS | 18 8<br>10 12 | 1.5 75% | | gravel (gm) - poorly sorted, 10% cobble<br>20% sand, 20% silt, 10% clay, firm friable | 1.3, 4.2<br>3.1 |
| 14 - 16<br>(13:35) | SS | 16 23<br>32 40 | 0.5 25% | | drove cobble - no recovery | |
| | | | | | Screen 5 - 15 feet bgs<br>Sand 16 - 4.5 feet bgs | |

| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
|---|---|---|---|
| JOB NO. | 20-42 | DATE DRILLED | April 24, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/ Darryl |
| BORING No. | VP - 10 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | VP - 10 same elevation as VP - 1<br><br>Main sand in VP-1 at 12' bgs.<br>sand in VP-1 at 8' bgs.<br><br>VP-10 drill to 7.5' bgs.<br>screen 7.5 - 4.5' bgs.<br>sand to 7.5 - 4' bgs. | |

| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
|---|---|---|---|
| JOB NO. | 20-42 | DATE DRILLED | April 29, 2000 |
| DRILLING Co. | Wright | DRILLER | |
| BORING No. | VP - 11 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | 5' from VP-6<br>sand in VP-6 at 10' | |
| | | | | | drill VP-6 to 8' | |
| | | | | | screen 8 - 4 ft. bgs. | |

ARS Technologies

SOIL BORING LOGS



| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | April 29, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/Darryl |
| BORING No. | VP - 12 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | VP - 12 1' lower than VP-6<br>sand at 10' - 9' ft. bgs. | |
| | | | | | VP-12 1' higher than VP-3<br>sand at 10 - 11 ft. bgs. | |
| | | | | | drill to 8' bgs. | |
| | | | | | screen to 4' bgs. | |

| | | | |
|---|---|---|---|
| **CLIENT** | METCALF & EDDY | **SITE** | GRANVILLE SOLVENTS |
| **JOB NO.** | 20-42 | **DATE DRILLED** | April 28, 2000 |
| **DRILLING Co.** | Wright | **DRILLER** | Densil/Darryl |
| **BORING No.** | VP - 1W | **DRILLING METHOD** | HSA |
| **GROUND ELEVATION** | | **WATER TABLE DEPTH** | |
| **FIELD SCIENTIST/ ENGINEER** | Mark Andrew (M&E)<br>Steve Markesic (ARS) | **ORGANIC VAPOR INSTRUMENT USED** | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| 0 - 2 (12:48) | SS | 7 14<br>11 11 | 1.5 75% | | Silty clay (cl), dark brown. 10% sand 20% silt, firm, dense, dry | 0.9, 1.0<br>0.9 |
| 2 - 4 (12:50) | SS | 4 8<br>8 9 | 1.5 75% | | Silty clay (cl), dark brown trace cobble 5% small gravel, 10% sand, 20% silt moist, dense, moderate soft | 1.3, 1.0<br>0.9 |
| 4 - 6 (12:55) | SS | 8 12<br>15 15 | 0.8 40% | | Sand with 40% gravel, 20% silt friable, sub angular to sub rounded | 1.2, 1.5<br>1.1 |
| 6 -8 (13:05) | SS | 5 9<br>13 16 | 1.0 50% | | sand & gravel, dark brown friable 5% cobble. 15% gravel, 10% silt, friable dry | @ 7'<br>4.6, 3.6 |
| 8 - 10 (13:15) | SS | 13 20<br>22 28 | 0.8 40% | | sand (sm) with 30% gravel, 10% silt friable moist | |
| 10 - 12 (13:28) | SS | 13 16<br>18 25 | 1.5 75% | | silty clay (cl), 10% small gravel, 10% sand 20% silt, firm, dense, moist<br>sandy at BHC - drill down to confirm sand drilled cobbles | 3.5, 2.7<br>1.1 |
| 12 - 14 (13:36) | SS | 18 20<br>20 22 | 1.5 75% | | Sand with gravel<br>EOB - no | |

ARS Technologies — SOIL BORING LOGS — Page 1 of 1

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | April 27, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/Darryl |
| BORING No. | VP-2 | DRILLING METHOD | HAS 4 1/4 |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION<br>3" split spoons | Remarks<br>PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| 0 - 2<br>(08:20) | 3"<br>SS | 3 5<br>8 13 | 18" 75% | | Top soil profile to silty clay (cl), dark reddish brown trace gravel; sand silt moderately firm, moist, dense | 6" - 1.7<br>12" - 1.1<br>18" - 1.9<br>24" - 1.<br>30" - 1.4<br>36" - 1.1<br>42" - 1.2<br>48" - 1.5<br>[moisture filled fx] |
| 2 - 4<br>(08:26) | SS | 6 10<br>12 15 | 2.0 100% | | Silty clay as above, dark reddish brown trace gravel, 10% sand, 20% silt moderately firm, dense, moist | |
| 4 - 6 | SS | 5 9<br>14 15 | 2.0 100% | | As above - moisture increases at base | |
| 6 - 8 | SS | 5 13<br>17 20 | 2.0 100% | | As above - silty clay, 15% small gravel 10% sand, 20% silt, firm, moist, dense | 6" - 2.0<br>12" - 1.6<br>18" - 1.1 |
| 8 - 10<br>(08:45) | SS | 9 15<br>17 15 | 2.0 100% | | 8 - 9 as above - silty clay<br>9 - 10 coarse gravel (gm), cobble 30% sand, 10% silt, poorly sorted sub angular | 2.4, 4.1 |
| 10 - 12<br>(08:55) | SS | 20 14<br>17 17 | 2.0 100% | | 10 - 12 coarse gravel - poorly sorted 30% sand, 20% silt, 10% clay not saturated - increase PID reading | 11, 9 |
| 12 - 14<br>(09:05) | SS | 16 18<br>20 22 | 0.2 0% | | cobble in soil - no recovery<br><br>Possible shift in pattern of drawing from orig. Layout. Orig. config. was MWVP to west. Drill new hole 5' from PF-002 which rotates Drawing 180°<br><br>Screen 4 - 14 feet bgs<br>Sand 2 - 12 feet bgs | |

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENT |
| JOB NO. | 20-42 | DATE DRILLED | April 28, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil, Darrel L |
| BORING No. | VP-3 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| | 3" | | | | Top soil profile to silty clay (cl), dark brown | 1.0, 1.2 |
| 0 -2 | SS | 5 5 | 1.5 25% | | firm, dense, dry | 1.0 |
| (09:57) | | 7 7 | | | 20% gravel, 10% sand, 20% silt | |
| 2 - 4 | SS | 2 3 | 2.0 100% | | Silty clay, dark reddish brown, medium soft, | 1.9, 2.2 |
| (10:03) | | 5 9 | | | dense, trace sand, 30% silt | 2.1 |
| 4 - 6 | SS | 6 9 | 1.5 25% | | Silty clay, trace sand, 30% silt, reddish brown | 1.1, 1.0 |
| (10:07) | | 13 14 | | | medium soft, dense, moist | 1.2 |
| 6 - 8 | SS | 9 12 | 2.0 100% | | | |
| (10:15) | | 13 15 | | | Silty clay, dark reddish brown, firm, dense | 0.9, 1.0 |
| | | | | | moist, 5% small gravel, 10% sand, 20% silt | 0.9 |
| 8 - 10 | SS | 10 18 | 1.5 75% | | | |
| (10:25) | | 13 13 | | | silty clay as above | 1.7, 1.0 |
| | | | | | | 1.7 |
| 10 - 12 | SS | 8 16 | 2.0 100% | | | |
| (10:30) | | 11 13 | | | 10 -10.3 gravel (gm) very poorly sorted | 1.7, 2.4 |
| | | | | | 20% sand, 20% silt, 20% clay | 3.9 |
| | | | | | 10.3 - 12 firm, dense, silty clay | |
| | | | | | measured sand % to base of sample | |
| 12 - 14 | SS | 9 13 | 2.0 100% | | Gravel (gm) with cobbles | 6.7, 3.4 |
| (10:34) | | 17 22 | | | 25% sand, 20% silt, friable dry | |
| | | | | | screen 14 - 4 ft. bgs | |
| | | | | | sand 14 - 4 ft. bgs | |

**ARS Technologies** **SOIL BORING LOGS** 

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | April 27, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil, Darrel L |
| BORING No. | VP-4 | DRILLING METHOD | HAS |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | 3" | | | | Top soil profile to silty clay, dark reddish | 1.0, 1.0 |
| 0 -2 | SS | 3 6 | 2.0 100% | | brown, trace gravel | 1.0 |
| (10:00) | | 6 8 | | | sand, 30% silt, firm | |
| 2 - 4 | SS | 5 7 | 2.0 100% | | Silty clay/silt, dark reddish brown | 1.0, 1.0 |
| (10.05) | | 9 11 | | | some roots, trace gravel, 10% sand, 25% silt | 2.7 |
| | | | | | dense moderate firm, moist | |
| 4 - 6 | SS | 3 9 | 2.0 100% | | As above - weathered till | 1.0, 1.0 |
| (10:08) | | 11 16 | | | | 0.9 |
| | SS | 3 7 | 2.0 100% | | Silty clay (cl) till, dark reddish brown | 1.0, 1.2 |
| 6 - 8 | | 12 20 | | | 10% small gravel, 15% sand, 20% silt | 1.9 |
| (10:12) | | | | | firm, dense and moist | |
| | SS | 16 7 | 1.0 50% | | | |
| 8 - 10 | | 8 7 | | | Silty clay (cl) with increased small gravel 20%, | 1.1, 1.4 |
| (10:20) | | | | | 10% sand, 20% silt, | 1.7 |
| | | | | | moist zone at mid sample (cm 8) | |
| | | | | | not as firm or dense as above (9-9.5) | |
| 10 - 12 | SS | 5 8 | 2.0 100% | | Gravel, very poorly sorted | 1.7, 3.1 |
| (10:28) | | 11 14 | | | 30% gravel, 20% sand, 10% silt | 2.5 |
| | | | | | moist, wet | |
| 12 - 14 | SS | 9 15 | 2.0 100% | | Silty clay (cl) | 4.8, 2.5 |
| (10:35) | | 15 18 | | | 10% coarse gravel, 20% sand, 20% silt | 1.7 |
| | | | | | firm, dense | |
| 14 - 16 | SS | 11 20 | 2.0 100% | | Gravel (gm) very poorly sorted | 7.1, 29.2 |
| (10:55) | | 33 40 | | | 20% coarse gravel, 25% sand, 20% silt | 3.1 |
| | | | | | not saturated | |
| | | | | | sand fill 16 - 15 ft. bgs. | |
| | | | | | screen 15 - 5 ft. bgs. | |
| | | | | | sand 16 - 4.5 ft. bgs. | |

**ARS Technologies** **SOIL BORING LOGS** 

| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
|---|---|---|---|
| JOB NO. | 20-42 | DATE DRILLED | April 28, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil, Darrel L |
| BORING No. | VP-5 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| | 3" | | | | Top soil profile to dark reddish brown, silty | 0.9, 0.9 |
| 0 - 2 (08:15) | SS | 4 6<br>7 8 | 1.5 25% | | clay (cl). Trace sand and 25% silt.<br>*firm, dense, moist* | 0.9, 0.9 |
| 2 - 4 (08:22) | SS | 7 8<br>10 10 | 2.0 100% | | Silty clay (cl), dark reddish brown<br>5% gravel, 10% sand, 20% silt, moist & dense | 0.9, 0.8<br>0.9 |
| 4 - 6 (8:28) | SS | 5 11<br>13 16 | 2.0 100% | | Silty clay (cl) at above 2 - 4 | 0.8, 1.3<br>1.0 |
| 6 - 8 (08:35) | SS | 15 15<br>11 15 | 2.0 100% | | 6 - 7.5 silty clay (cl) as above<br>7.5 - 8 softer and increased moisture | 1.3, 21<br>1.5 |
| | | | | | 8 -9 soft silty clay (cl) zone with increasing moisture. Sand seam at base 2" ±. | 0.8, 1.1<br>2.9 |
| | | | | | 9 - 10 sandy silty clay<br>5% small gravel, 30% sand, 10% silt<br>friable, firm , dense and dry. | |
| 10 - 12 (08:49) | SS | 8 13<br>15 16 | 1.5 25% | | 10 - 10.5 Silty clay with gravel<br>10.5 - 12 sand with gravel<br>10% silt, friable dry, split cobble | 1.9, 2.3 |
| 12 - 14 (08:51) | SS | 14 16<br>20 25 | 2.0 100% | | sand (sm) with 30% gravel, 20% silt<br>friable dry, sub rounded very poorly sorted | 8.5,. 3.5<br>8.9 |
| 14 - 16 (09:08) | SS | 22 19<br>20 22 | 2.0 100% | | as above - dry sand & gravel (small - 6m) | 6, 5, 9 |
| | | | | | screen 16 - 6 ft. bgs<br>sand 16 - 5.5 ft. bgs | |

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | |
| DRILLING Co. | Wright | DRILLER | Densil/ Darryl |
| BORING No. | VP - 6 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|
| | | | | | (MW on 3 - 4' apparent file) | 1.2, 1.9 |
| 0 - 2' (14:29) | SS | 4 8<br>10 13 | 1.5 75% | | Top soil profile to silty clay (cl), dark reddish Brown with 10% small gravel, 20% sand 20% silt, firm, dense | 1.2<br><br>1.2, 0.8 |
| 2 - 4' (14:35) | SS | 7 11<br>10 12 | 1.5 75% | | Silty clay (cl) as above, 5% small gravel, 10% sand, 20% silt dark reddish brown, firm, dense, moist | 0.9<br><br>1.0, 1.4 |
| 4 - 6' (14:40) | SS | 4 8<br>11 14 | 2.0 100% | | Silty clay (cl) in situ firm, dense, moist, dark reddish brown, trace gravel, 10% sand, 20% silt | 2.9 |
| 6 - 8' (14:45) | SS | 4 8<br>11 13 | 2.0 100% | | Silty clay (cl), dark reddish brown, 5% small gravel, 10% sand, 20% silt, firm, dense, moist | 1.9, 1.9<br>1.8 |
| 8 - 10' (14:53) | SS | 12 15<br>12 9 | 2.0 100% | | silty clay as above, soft slightly sandy section at 9.5 - 10', moist - wet | 3.5, 2.5<br>1.7<br>8.5, 15.0 |
| 10 - 12' (15:00) | SS | 12 13<br>12 22 | 1.5 20% | | Gravel (gm) very poorly sorted damp, 20% sand, 20% silt, 10% clay rock in soil | 6.8<br><br>19.8 |
| 12 - 14' | SS | 17 50/3 | 1.0 50% | | Gravel as above, drilled hard at 13' | |
| 14 - 16' (15:15) | SS | 17 12<br>12 18 | 2.0 100% | | Silty clay (cl) 20% gravel, 20% sand 20% silt, friable loose, damp | 3 6 4 4 |
| | | | | | 15 - 5' bgs. - Screen<br>16 - 4.5' bgs. - Sand | |

| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
|---|---|---|---|
| JOB NO. | 20-42 | DATE DRILLED | April 28, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/ Darryl |
| BORING No. | VP - 8 | DRILLING METHOD | HAS |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | PID |

| Depth (ft) | Sample No. | Blows/ 6 inches | | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks PID measurements (ppmv) |
|---|---|---|---|---|---|---|---|
| | 3" | | | | | Silty clay (cl) | |
| 0 -2 (14:11) | SS | 3<br>7 | 7<br>11 | 2.0 -100% | | 5% gravel, 10% sand, 20% silt<br>firm, dense, moist | 1.6, 1.2 |
| 2 - 4 (14:16) | SS | 4<br>6 | 5<br>8 | 2.0 - 100% | | silty clay (cl) dark reddish brown<br>10% large gravel, 10% sand, 15% sand<br>dense, wet | 1.1, 0.9<br>1.1, 1.2 |
| 4 - 6 (14:24) | SS | 3<br>8 | 7<br>16 | 1.5 - 75% | | mid soft - more gravel at base<br>silty clay 4 -5 as above<br>sand + gravel 5 -6 poorly sorted, sub rounded | 0.8, 0.7<br>0.9 |
| 6 - 8 (14:30) | SS | 18 | 50/ | 0 | | No recovery | |
| 8 - 10 (14:37) | SS | 8<br>15 | 12<br>17 | 2.0 - 100% | | Sand & gravel (sm/cm)<br>20% silt, 10% clay poorly sorted | 4.5, 17.3<br>6.5 |
| 10 - 12 (14:43) | SS | 12<br>20 | 16<br>28 | 0.5 - 25% | | as above (sand & gravel) | 4.5 |
| 12 - 14 (14:53) | SS | 27<br>16 | 20<br>16 | 2.0 - 100% | | as above - poorly sorted sand & gravel<br>20% cobble, 20% gravel, 20%sand, 20% silt,<br>20% clay | 4.5, 5.6 |
| 14 -16 (15:00) | SS | 27<br>20 | 25<br>20 | 2.0 - 100% | | as above | 2.4, 4.2 |
| 16 - 18 (15:10) | SS | 14<br>9 | 14<br>12 | 2.0 - 100% | | as above - moisture increases | 3.9, 4.2 |
| 18 -20 (15:20) | SS | 8<br>10 | 8<br>14 | 2.0 - 100% | | " | 4.8, 1.5<br>9.0 |
| 20 -22 (15:28) | SS | 5<br>10 | 10<br>18 | 2.0 - 100% | | "<br>as above | 10, -22, -15 |
| 22 - 24 | SS | 8<br>14 | 14<br>14 | 2.0 - 100% | | water at 23.5<br>screen 20 -5 ft. bgs.<br>drill to water - 15' vadose screen | |

**ARS Technologies** **SOIL BORING LOGS** 

| | | | |
|---|---|---|---|
| **CLIENT** | METCALF & EDDY | **SITE** | 5' SW OF PF-1 |
| **JOB NO.** | 20-42 | **DATE DRILLED** | APRIL 29, 2000 |
| **DRILLING Co.** | Wright | **DRILLER** | Densil/ Darryl |
| **BORING No.** | VP - 9 | **DRILLING METHOD** | HSA |
| **GROUND ELEVATION** | | **WATER TABLE DEPTH** | |
| **FIELD SCIENTIST/ ENGINEER** | Mark Andrew (M&E)<br>Steve Markesic (ARS) | **ORGANIC VAPOR INSTRUMENT USED** | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | 6" lower than VP-5<br>sand in VP-5 at 10.5<br>say 10 in #9<br><br>18" higher than VP-7<br>sand in VP-7 at 8'<br>say 9.5 in #9<br><br>drill to 8'<br>4' screen<br>4.5 sand<br><br>1 foot lower than PF-1<br>5' depth = PF-1 = 4' in VP-9 | |

**ARS Technologies** **SOIL BORING LOGS** Page 1 of 1

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | APRIL 29, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/Darryl |
| BORING No. | PF - 1 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | Depth to sand VP-5: 10.5'<br>location PF - 1: 1' higher than VP-5<br>Sand at 11.5<br>drill to 9.5 - pull out<br>leave open<br><br>To - 9.5 feet. | |

**ARS Technologies** **SOIL BORING LOGS** Page 1 of 1

| | | | |
|---|---|---|---|
| CLIENT | METCALF & EDDY | SITE | GRANVILLE SOLVENTS |
| JOB NO. | 20-42 | DATE DRILLED | April 29, 2000 |
| DRILLING Co. | Wright | DRILLER | Densil/Darryl |
| BORING No. | PF - 2 | DRILLING METHOD | HSA |
| GROUND ELEVATION | | WATER TABLE DEPTH | |
| FIELD SCIENTIST/ ENGINEER | Mark Andrew (M&E)<br>Steve Markesic (ARS) | ORGANIC VAPOR INSTRUMENT USED | |

| Depth (ft) | Sample No. | Blows/ 6 inches | Adv./ Recovery | VOC (ppmv) | SOIL DESCRIPTION | Remarks |
|---|---|---|---|---|---|---|
| | | | | | 6" lower than VP-7<br>sand in VP-7 at 8' bgs.<br>1' lower than VP-6<br>sand in VP-6 at 10' bgs.<br><br>Same elevation as VP - 001<br><br>sand dips down to east<br>sand dips up to west<br><br>Drill PF-2 to 7.5' bgs. | |

# APPENDIX B

## Methods and Calculations for the

## Sand Unit

## Soil Vapor Extraction Pilot Test,

## Granville Solvents Project, Granville Solvents Site,

## Granville, Ohio.

# AIR PERMEABILITY TESTING

## INTRODUCTION

On May 4 and June 28, 2000, Metcalf & Eddy, Inc, (M&E) conducted air permeability tests at the former Granville Solvents Site on the sandy soils encountered at approximately 8 feet below ground surface. The results of the transient air injection tests indicated that the unsaturated portion of the sand and gravel unit encountered at approximately 8 feet below grade has a bulk air permeability of approximately $1.4 \times 10^{-9}$ $m^2$ or 1400 darcies, with an equivalent water conductivity of approximately $1.2 \times 10^{0}$ cm/s. The results of the steady state vacuum tests indicated that the unsaturated portion of the sand and gravel unit encountered at approximately 8 feet below grade has a bulk air permeability of approximately $2.3 \times 10^{-9}$ $m^2$ or 2300 darcies, with an equivalent water conductivity of approximately $1.9 \times 10^{0}$ cm/s. These results are indicative of a very permeable soil which can be effectively treated with conventional soil vapor extraction. M&E believes that both the transient and steady state tests overestimated the permeability of the soils due to well losses inherent in the 2-inch test well and potential air leaks to the surface through the less permeable cap soils.

## METHODS

### Principles of Air Permeability Testing

Both air and water permeability tests are typically conducted by employing an injection or extraction well and one or more observation wells located at various distances and directions from the injection/extraction well. The blower or pump is turned on, and the response to the injection or extraction is periodically recorded at the observation wells for the duration of the test. The magnitude of the response and the time required to achieve steady state conditions at an individual well may vary with the distance to the pumped well and the distribution of geologic heterogeneities.

Air permeability testing provides data on the air permeability of the tested geologic unit or units. The data are also used to estimate the radius of influence of the venting configuration, anticipated airflow rates, moisture removal rates, and initial contaminant removal rates. Air permeability is typically evaluated using analytical solutions for radial flow to a well. The equation used must simulate the boundaries (zones of relative impermeability) encountered at the site. Typical boundaries are a fine-grained unit above the tested zone, and the intersection of the tested zone with the water table.

The test methods used here are modifications of Darcy's law and equations for steady-state radial flow to or from a vent well. The transient solution is based on accurately recording the dynamic response of the soil to a constant injection or extraction rate. Automatic data loggers are commonly used to obtain this dynamic response data.

**Preparations at the Granville Site**

On May 4, 2000, two steady state tests were conducted at wells VP-8 and MW-P1. For the first test, 9.5 inches of water column vacuum was applied to well VP-8 for 15 hours beginning May 3. Vacuum measurements were taken at wells VP-1,2,3,4,7,9,10,11 and 12, at MW-1,2,3 and 5, at PF-1 and PF-2, and at MW-P1. The second test was conducted as a short-term step test. The vacuum applied at VP-8 was increased every half hour, beginning at 1.6 inches of water, increased to 5.5 inches, and finally to 9.5 inches of water column. Vacuum influence was monitored at wells VP-7, VP-9, VP-13, and MW-P1. Figure 1 presents the data taken at the end of the 15-hour test.

Before running the injection tests, vacuum measurements were taken at most of the regularly monitored wells, including those wells to be used for the tests. These readings confirmed the presence of a subsurface connection between VP-8, the vent well, and the observation wells to be used for the tests. Readings of airflow and vacuum from VP-8 were also taken. The intake and exhaust lines from the blower were then reversed, so that *air would be forced into* VP-8. *Testing at* VP-8 *(Figure 2) showed that full pressurization* of the well occurred in 0.05 minutes, approximately 5% of the time required to achieve full response at the observation wells. Each test lasted 20 minutes. Air pressure readings were taken during the tests at wells VP-1, VP-3, VP-7, VP-8, VP-13, MW-1 and MW-P1. The readings were taken using both automatic and manual instruments.

## Equipment

For the steady-state tests, data were collected using a Dwyer digital manometer. Pressure readings taken during the transient tests were recorded by three PXD-260 10 psi transducers manufactured by In-Situ, Inc., of Laramie, Wyoming. The transducers were connected to an In-Situ Hermit SE2000 data logger. Occasional readings were also taken during the tests with a Dwyer digital manometer.

The transducers were connected to the wells by securing the 1/4-inch npt male threaded ends on each transducer to a 1/4-inch female npt fitting on an airtight cap on each tested well. A sampling port was installed on a threaded brass tee between the transducer and the well to allow for corroborative readings with the digital manometer. All connections were sealed with teflon tape.

## The Tests

During the 15-hour steady-state test, readings were taken at the observation wells at approximately 1/2-hour intervals for the first 3 hours. A final set of readings was taken on May 4.

For the transient tests, the Hermit was programmed so that pressure readings were taken and recorded on a logarithmic time scale. Readings were taken at the following rates:

| Elapsed Time | Sample Interval |
|---|---|
| 0-20 seconds | 0.5 second |
| 20-60 seconds | 1 second |
| 1-10 minutes | 12 seconds |
| 10-100 minutes | 2 minutes |

The tests were run for 20 minutes. The time required to reach the highest recorded magnitude of response at each well was about 1 minute.

A total of nine transient tests were run. Some tests were run as the blower was turned off (depressurization tests). The wells tested and transducers used are listed in Table 1. The data from the tests in bold print were used in the air permeability calculations.

**Table 1**

| Test Number | Type | Transducer 1 | Transducer 2 | Transducer 3 |
|---|---|---|---|---|
| 0 | Pressurization | VP-8 | VP-8 | VP-8 |
| 1 | Pressurization | VP-8 | VP-8 | VP-8 |
| 2 | Pressurization | MP-1 | **MW-13** | atmosphere |
| 3 | Pressurization | VP-13 | **MW-P1** | atmosphere |
| 4 | Depressurization | VP-13 | MW-P1 | atmosphere |
| 5 | Pressurization | **VP-1** | **VP-3** | **VP-7** |
| 6 | Depressurization | VP-1 | VP-3 | VP-7 |
| 7 | Pressurization | VP-1 | MW-1 | VP-7 |
| 8 | Depressurization | VP-1 | MW-1 | VP-7 |

## Data Collection

Table 2 lists the data obtained by the Hermit transducers and the digital manometer readings taken at each well.

**Table 2**

| Well | Pressure (Hermit) (inches of water col.) | Pressure (Manometer) (inches of water col.) |
|---|---|---|
| VP-8 | 12.8 | 8.7 |
| VP-1 | 0.14 | 0.17 |
| VP-3 | 0.11 | 0.17 |
| VP-7 | 0.18 | 0.22 |
| VP-13 | 0.24 | 0.16 |
| MW-P1 | 0.30 | 0.30 |
| MW-1 | 0.07 | NM |

The data show a reasonably good correlation between the two data sets at the observation wells. The cause of the variation at VP-8 is likely due to improper setup of the transducers at this well.

Figure 3 shows the response curve for well VP-3, plotted as inches of water column vs. the logarithm of time in minutes. The recorded pressure in the well decreased after about three to five minutes. This may be due to instrument drift, as the later time manometer readings indicated that the wells remained pressurized.

Figure 4 presents the section of the VP-3 graph used for the air permeability calculations, plotted as pressure in g/cm-s$^2$ (P') vs. the logarithm of time in minutes (ln(t)). The time interval chosen for each calculation was determined to best represent the response to pressurization in each well. A computer generated trendline is displayed, with the equation for the line in slope intercept form. The $R^2$ value is a measure of how well the line fits the data. $R^2$ values for the tests used ranged from 0.7143 to 0.8181, indicating reasonably good fits between the trendlines and the data sets. The exception was the trendline for well MW-1, with an $R^2$ value of 0.2257. The trendline for the MW-1 data was not used to calculate permeability.

## Transient Calculation of Permeability

The methods for air permeability are based on those provided by the Air Force Center for Environmental Excellence publication *Test Plan and Technical Protocol For A Field Treatability Test For Bioventing, May 1992.*

$$k = Qu/4\pi Am$$

where:

$k$ = air permeability ($cm^2$)
$Q$ = volumetric flow rate to/from the vent well ($cm^3/s$)
$A$ = slope of the dynamic range of $P'$ vs. $\ln(t)$
$P'$ = guage pressure at an observation well at time t ($g/cm\text{-}s^2$)
$m$ = stratum thickness (cm)
$u$ = viscosity of air ($1.8 \times 10^{-4}$ g/cm-s at 18° C)

For well VP-3:

$$k = \frac{(54{,}075.96\ cm^3/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi\ (88.80\ g/cm\text{-}s^2)(457.2\ cm)}$$

$$k = 1.91 \times 10^{-5}\ cm^2 = 1.91 \times 10^{-9}\ m^2 = 1934.55 \text{ darcies}$$

The results of the transient air permeability calculations are summarized in Table 3.

**Table 3**

| Well | Air Permeability ($m^2$) | Water Permeability (cm/sec) | Pressure (inches of water) | Slope of P' vs. ln(t) | $R^2$ |
|---|---|---|---|---|---|
| VP-1 | $1.49 \times 10^{-9}$ | $1.27 \times 10^{0}$ | 0.14 | 113.56 | 0.7248 |
| VP-3 | $1.91 \times 10^{-9}$ | $1.63 \times 10^{0}$ | 0.11 | 88.80 | 0.8181 |
| VP-7 | $1.33 \times 10^{-9}$ | $1.14 \times 10^{0}$ | 0.18 | 126.91 | 0.8041 |
| VP-13 | $1.33 \times 10^{-9}$ | $1.14 \times 10^{0}$ | 0.24 | 127.11 | 0.7143 |
| MW-P1 | $9.99 \times 10^{-10}$ | $8.53 \times 10^{-1}$ | 0.30 | 169.20 | 0.7261 |

Calculation sheets, graphs, and raw data sets for each transient calculation are located in Appendix B-1.

**Steady State Calculation of Permeability**

The theoretical basis for these calculations is provided in the Unaited States Army Corps of Engineers publication *Soil Vapor Extraction and Bioventing Manual*, Chapter 2.

**Calculation for VP-3**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:

$$k_a = \frac{Q_v \, P^* \, u \ln(r_e/r)}{\pi \, b \, (P^2 - P_{atm}^2)}$$

where: $Q_v$ = volumetric flow rate ($m^3$/sec)
$P^*$ = absolute pressure at the point of flow measurement, adjusted for well loss (kg/m $sec^2$)
$P$ = absolute pressure at the observation well. (kg/m $sec^2$)
$P_{atm}$ = atmospheric pressure during test (kg/m $sec^2$)
$u$ = dynamic viscosity of soil gas (kg/m sec)
$\pi$ = 3.1415926
b = Aquifer thickness(m)
$r_e$= radius of pressure influence (m)
r = Distance from VP-8 to observation well (m)

$k_a$ = apparent air permeability ($m^2$)

| | | | | |
|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 scfm | = | 0.050211 $m^3$/sec |
| | $P_{atm}$ = | 29.54 in Hg | = | 99990.27 kg/m $sec^2$ |
| | P*diff = | 8.50 in H20 | = | 2116.442 kg/m $sec^2$ |
| | $u$ = | 1.77E-05 kg/m sec | | |
| | b = | 10 feet | = | 3.048 m |
| | $r_e$ = | 430.8 feet | = | 131.3078 m |
| | r = | 69.5 feet | = | 21.1836 m |
| | P diff = | 0.2 in $H_2O$ | = | 49.79865 kg/m $sec^2$ |
| Calculated: | P* = | 97873.83 kg/m $sec^2$ | | |
| | P = | 99940.47 kg/m $sec^2$ | | |
| | $k_a$ = | 1.67E-09 $m^2$ | = | 1689.798 darcies |

The results of the steady state air permeability calculations are summarized in Table 4.

**Table 4**

| Well | Air Permeability ($m^2$) | Water Permeability (cm/sec) | Vacuum (inches of water) | Distance From VP-8 (feet) |
|---|---|---|---|---|
| VP-1 | 1.78E-09 | 1.52E+00 | 0.20 | 61.5 |
| VP-2 | 2.86E-09 | 2.44E+00 | 0.12 | 66.0 |
| VP-3 | 1.67E-09 | 1.42E+00 | 0.20 | 69.5 |
| VP-4 | 2.24E-09 | 1.92E+00 | 0.16 | 60.5 |
| VP-7 | 1.98E-09 | 1.69E+00 | 0.22 | 40.0 |
| MW-P1 | 1.96E-09 | 1.67E+00 | 0.26 | 26.5 |
| MW-1 | 1.72E-09 | 1.47E+00 | 0.11 | 153.0 |
| MW-2 | 4.85E-09 | 4.14E+00 | 0.04 | 149.0 |
| MW-3 | 1.32E-09 | 1.12E+00 | 0.15 | 146.5 |
| MW-5 | 2.10E-09 | 1.79E+00 | 0.07 | 193.0 |

Calculation sheets and graphs for each calculation are located in Appendix B-2.

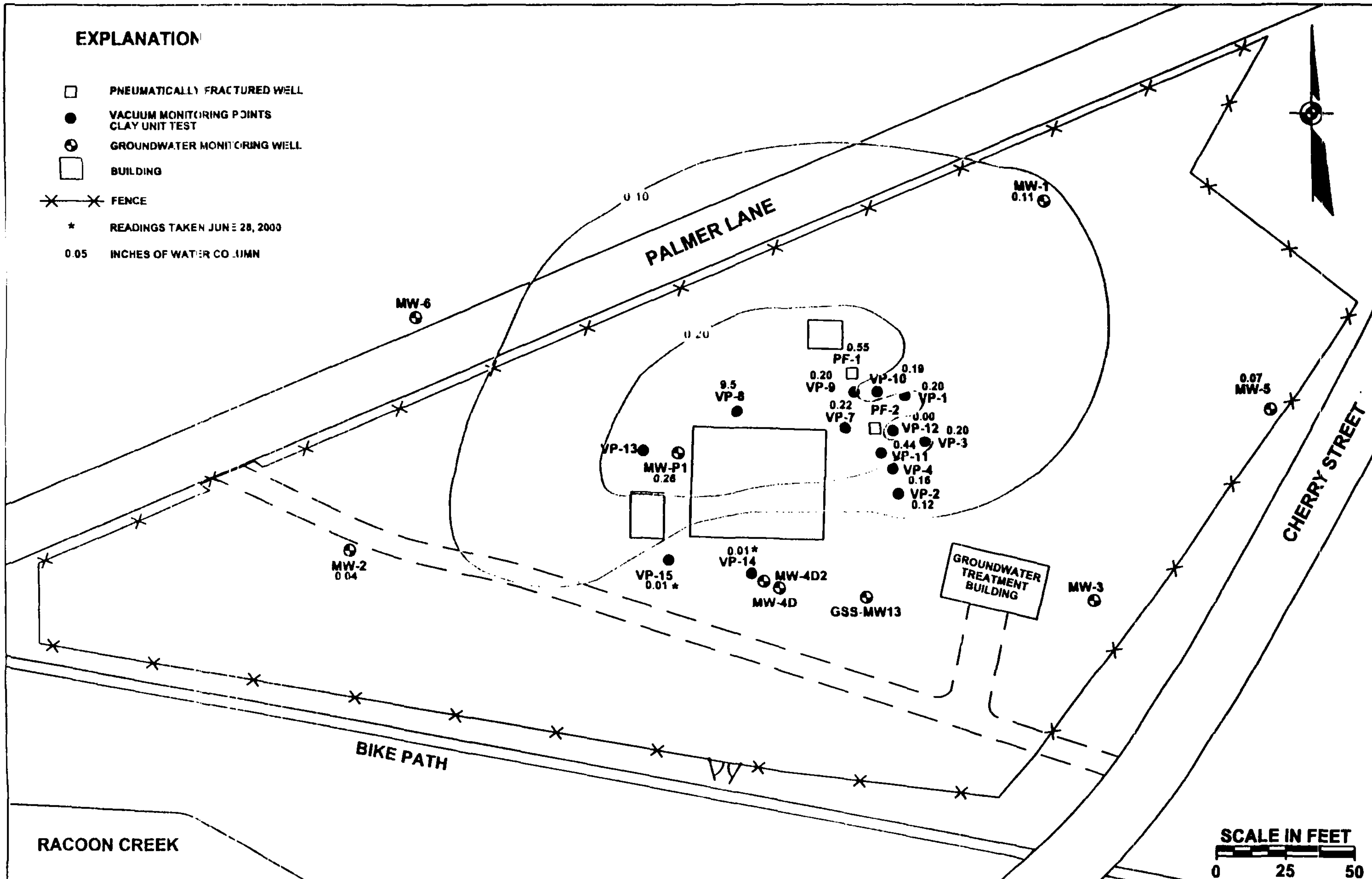
## Discussion

The air permeability results from the steady state and transient tests are about 2.5 orders of magnitude higher than expected for the tested soils. Air permeability values on the order of $10^{-9}$ m$^2$ ($10^{-13}$ cm$^2$) were expected, with equivalent water conductivities ($K_w$) on the order of $10^{-3}$ cm/s.

The higher than expected permeability values could have been caused by loss of vacuum to the ground surface, boundary effects of a limited area where the sand is present, or by well losses present in the extraction well. A decrease in the slope of the pressure vs. time trendline results in an increased value of the calculated air permeability. While the permeability calculated by both the transient and steady state methods were higher than expected, the tests clearly confirmed that the tested soils are suitable for conventional soil vapor extraction.

The effect of pressurization was measurable at MW-1, showing that the radius of influence of the injection tests was at least 145 feet in the direction of this well. A distance-drawdown plot (Appendix B-2), generated using the steady state data, indicates that the radius of influence of the steady-state test was 430 feet.

# FIGURES




M&E
Metcalf & Eddy

GRANVILLE SOLVENTS SITE
MAY 4, 2000
STEADY STATE VACUUM READINGS
GRANVILLE, OHIO

| Project Number | |
|---|---|
| 025508 | |
| File Name | Figure |
| 25508SSVFIG1 | 1 |

**Figure 2**
**Granville Solvents**
**Air Injection Permeability Tests Field Data**
**Well VP-8**

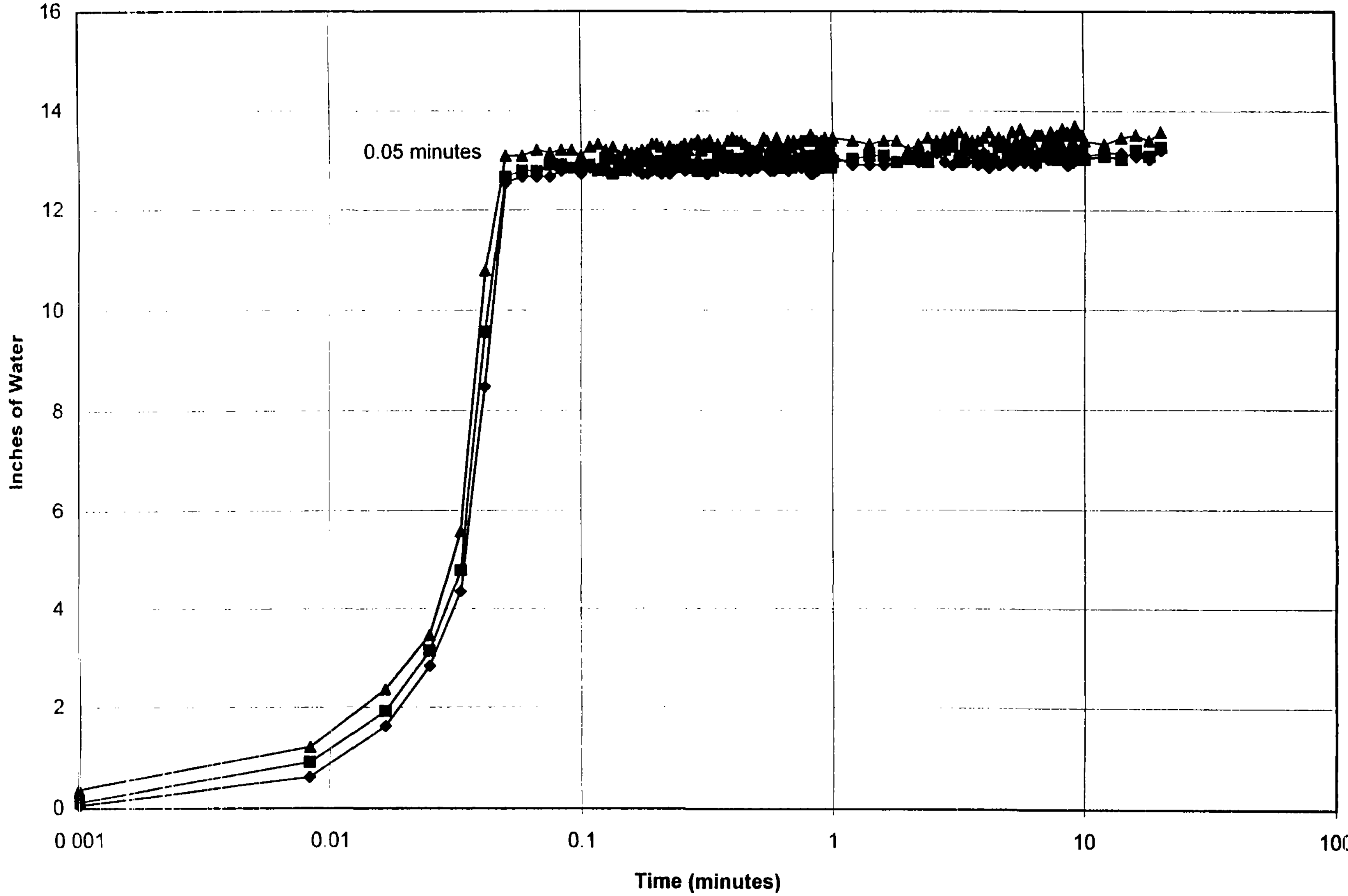
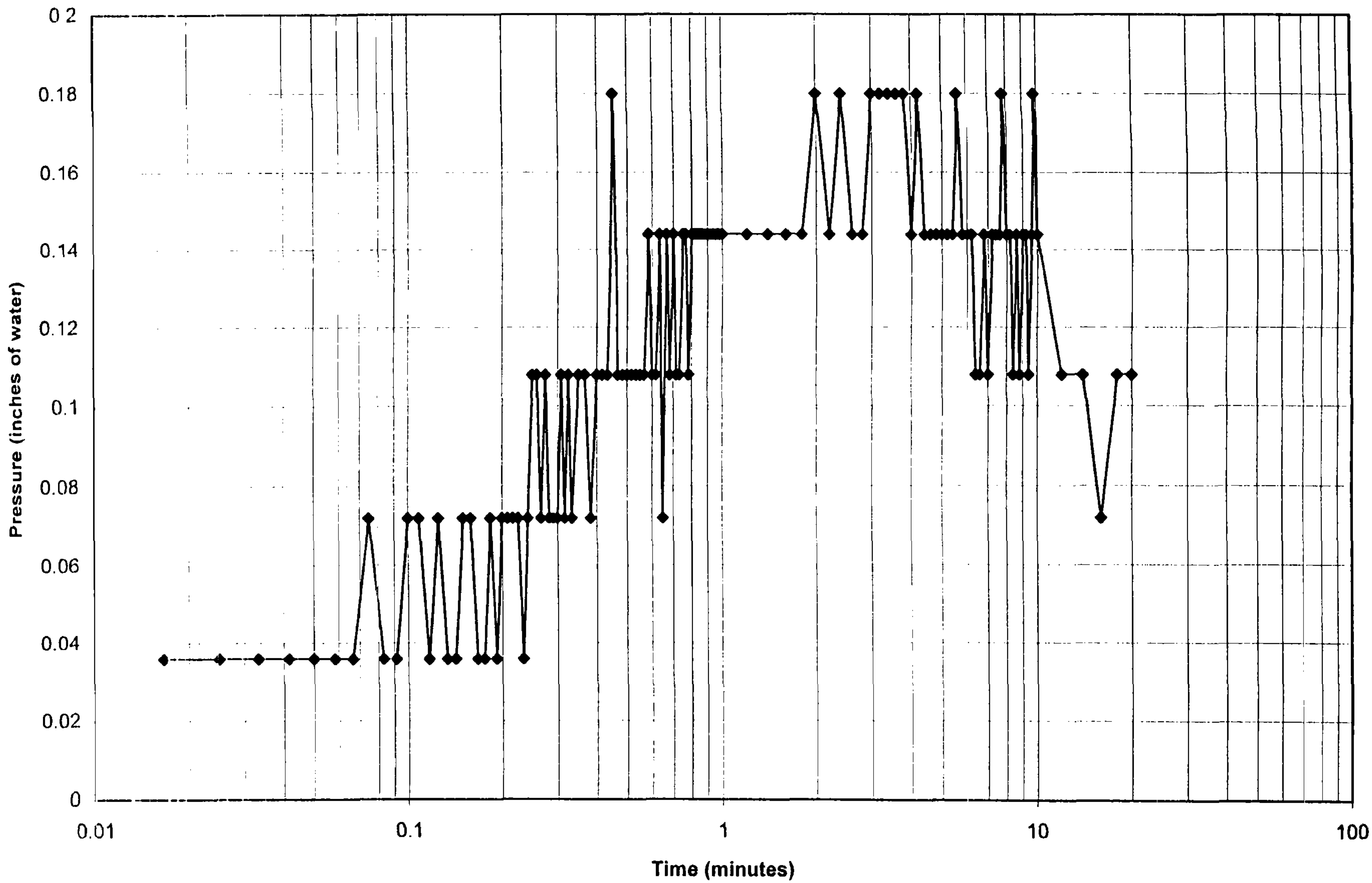
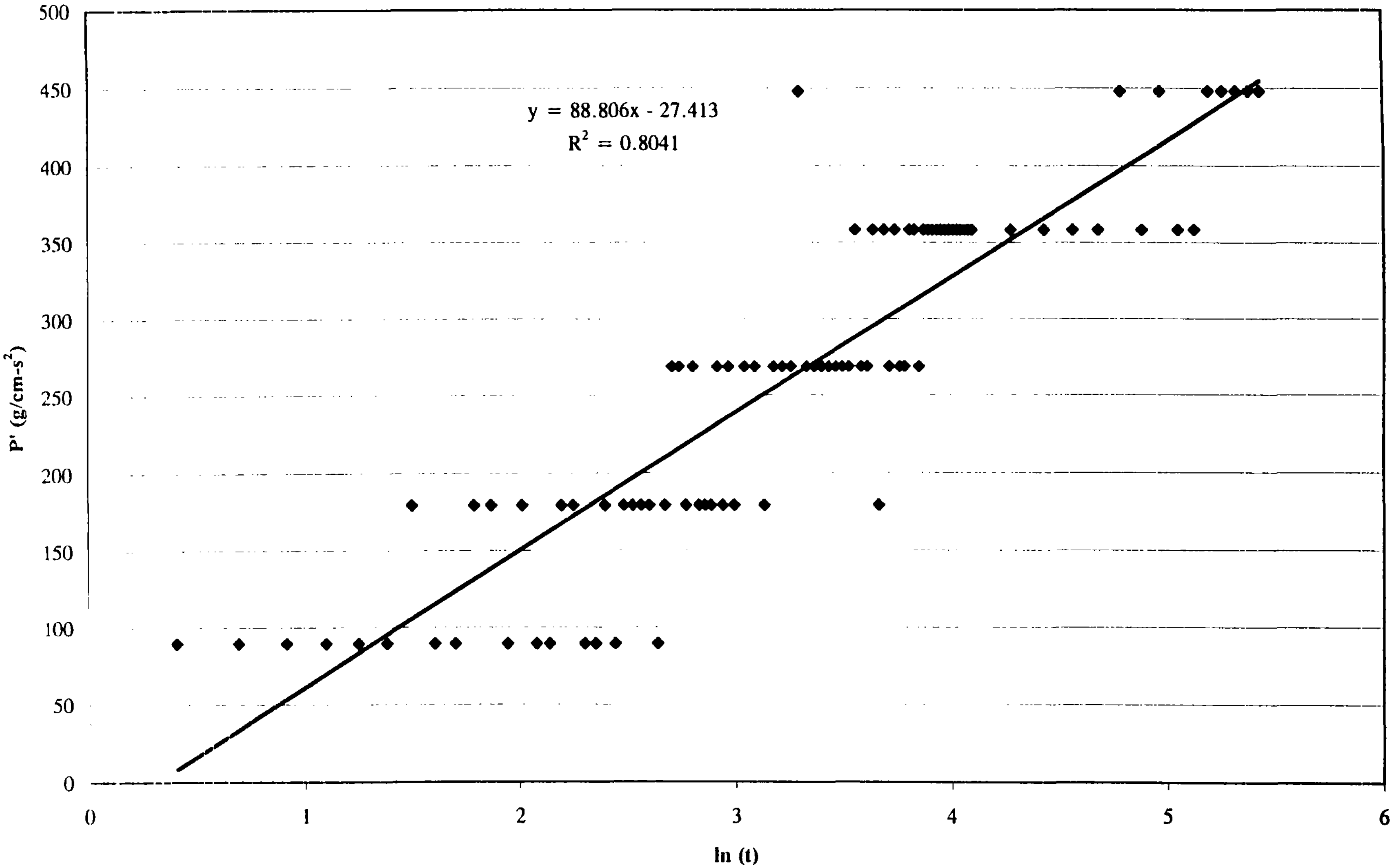


**Figure 3**
**Granville Solvents**
**Air Injection Permeability Tests Field Data**
**Well VP-3**



# Figure 4
# Granville Solvents
# Air Injection Permeability Tests
# Response Data
# Well VP-3



# APPENDIX B-1

# TRANSIENT CALCULATIONS

**Air Permeability Calculations**

From the AFCEE publication *Test Plan and Technical Protocol For A Field Treatability Test For Bioventing, May 1992*:

$$k = Qu/4\pi Am$$

where:

$k$ = air permeability ($cm^2$)
$Q$ = volumetric flow rate to/from the vent well ($cm^3/s$)
$A$ = slope of the dynamic range of $P'$ vs. $\ln(t)$
$P'$ = guage pressure at an observation well at time t ($g/cm\text{-}s^2$)
$m$ = stratum thickness (cm)
$u$ = viscosity of air ($1.8 \times 10^{-4}$ g/cm-s at 18° C)

For well P1:

$$k = \frac{(54{,}075.96\ cm^3/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi(113.56\ g/cm\text{-}s^2)(457.2\ cm)}$$

$$k = \frac{9.73\ cm^2 g/s^2}{4\pi(51{,}919.6\ g/s^2)}$$

$$k = 1.49 \times 10^{-5}\ cm^2 = 1.49 \times 10^{-9}\ m^2 = 1509.15 \text{ darcies}$$

$$Ka = 83.56 \text{ cm/sec}$$

$$Kw = 1.27 \times 10^{0} \text{ cm/sec}$$

For well P3:

$$k = \frac{(54{,}075.96\ cm^3/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi(88.80\ g/cm\text{-}s^2)(457.2\ cm)}$$

$$k = \frac{9.73 cm^2 g/s^2}{4\pi(40599.36\ g/s^2)}$$

$$k = 1.91 \times 10^{-5}\ cm^2 = 1.91 \times 10^{-9}\ m^2 = 1934.55 \text{ darcies}$$

$$Ka = 107.12 \text{ cm/sec}$$

$$Kw = 1.63 \times 10^{0} \text{ cm/sec} = 1934.55 \text{ darcies} \times 0.0008421$$

For well P7:

$$k = \frac{(54{,}075.96\ cm^3/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi(126.91\ g/cm\text{-}s^2)(457.2\ cm)}$$

$$k = \frac{9.73\ cm^2 g/s^2}{4\pi(58{,}023.25\ g/s^2)}$$

$k = 1.33 \times 10^{-5}\ cm^2 = 1.33 \times 10^{-9}\ m^2 = 1347.09$ darcies

$Ka = 74.59$ cm/sec

$Kw = 1.14 \times 10^{0}$ cm/sec

For well P13:

$$k = \frac{(54.075.96\ cm^3 g/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi(127.11\ g/cm\text{-}s^2)(457.2\ cm)}$$

$$k = \frac{9.73\ cm^2/s^2}{4\pi(58114.69\ g/s^2)}$$

$k = 1.33 \times 10^{-5}\ cm^2 = 1.33 \times 10^{-9}\ m^2 = 1347.09$ darcies

$Ka = 74.59$ cm/sec

$Kw = 1.14 \times 10^{0}$ cm/sec

For well MW-P1:

$$k = \frac{(54{,}075.96\ cm^3/s)(1.8 \times 10^{-4}\ g/cm\text{-}s)}{4\pi(169.2\ g/cm\text{-}s^2)(457.2\ cm)}$$

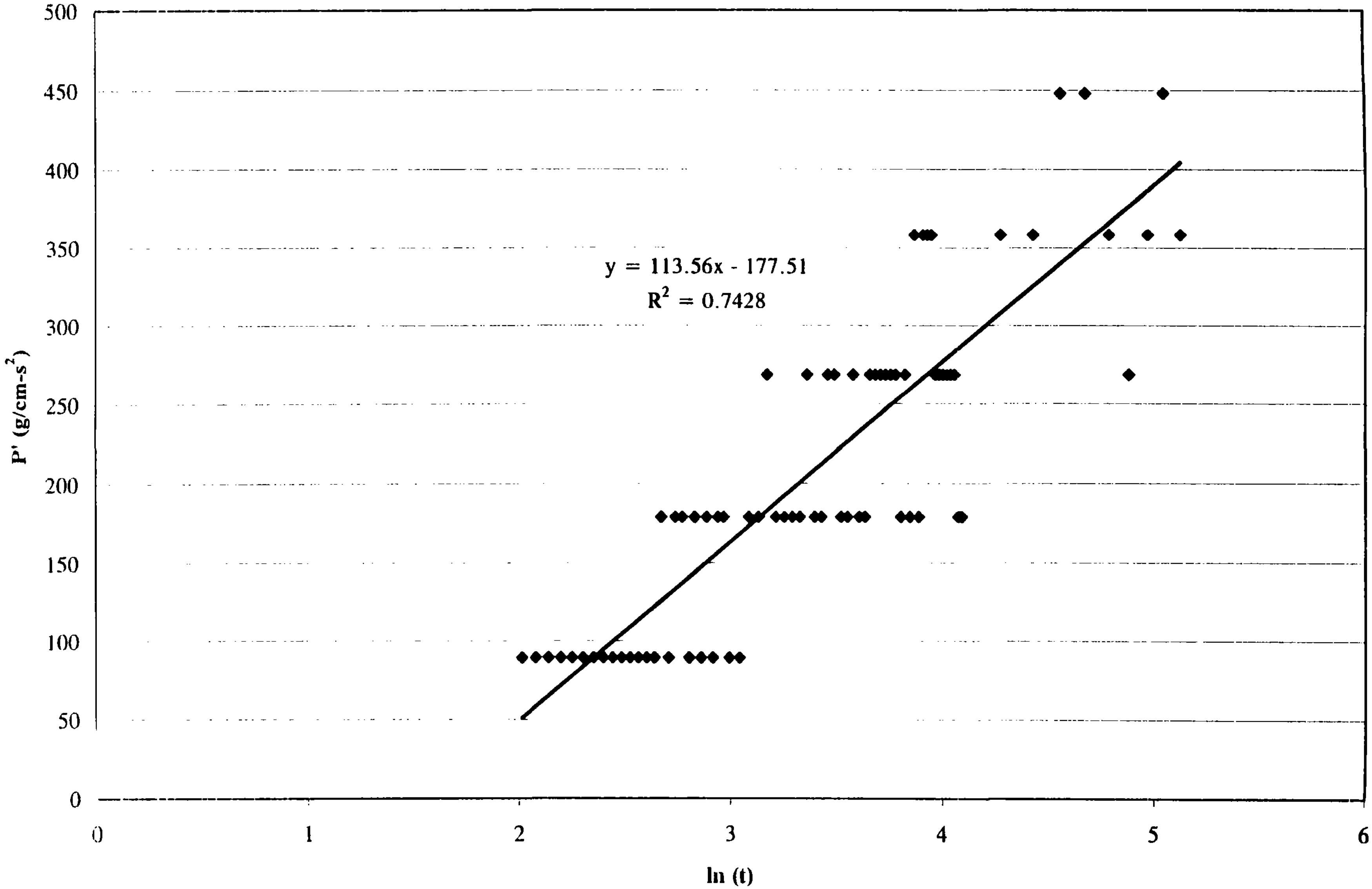
$$k = \frac{9.73\ cm^2 g/s^2}{4\pi(77358.24\ g/s^2)}$$

$k = 9.99 \times 10^{-6}\ cm^2 = 9.99 \times 10^{-10}\ m^2 = 1011.84$ darcies

$Ka = 59.03$ cm/sec

$Kw = 8.53 \times 10^{-1}$ cm/sec

## Granville Solvents
## Air Injection Permeability Tests
## Response Data
## Well VP-1



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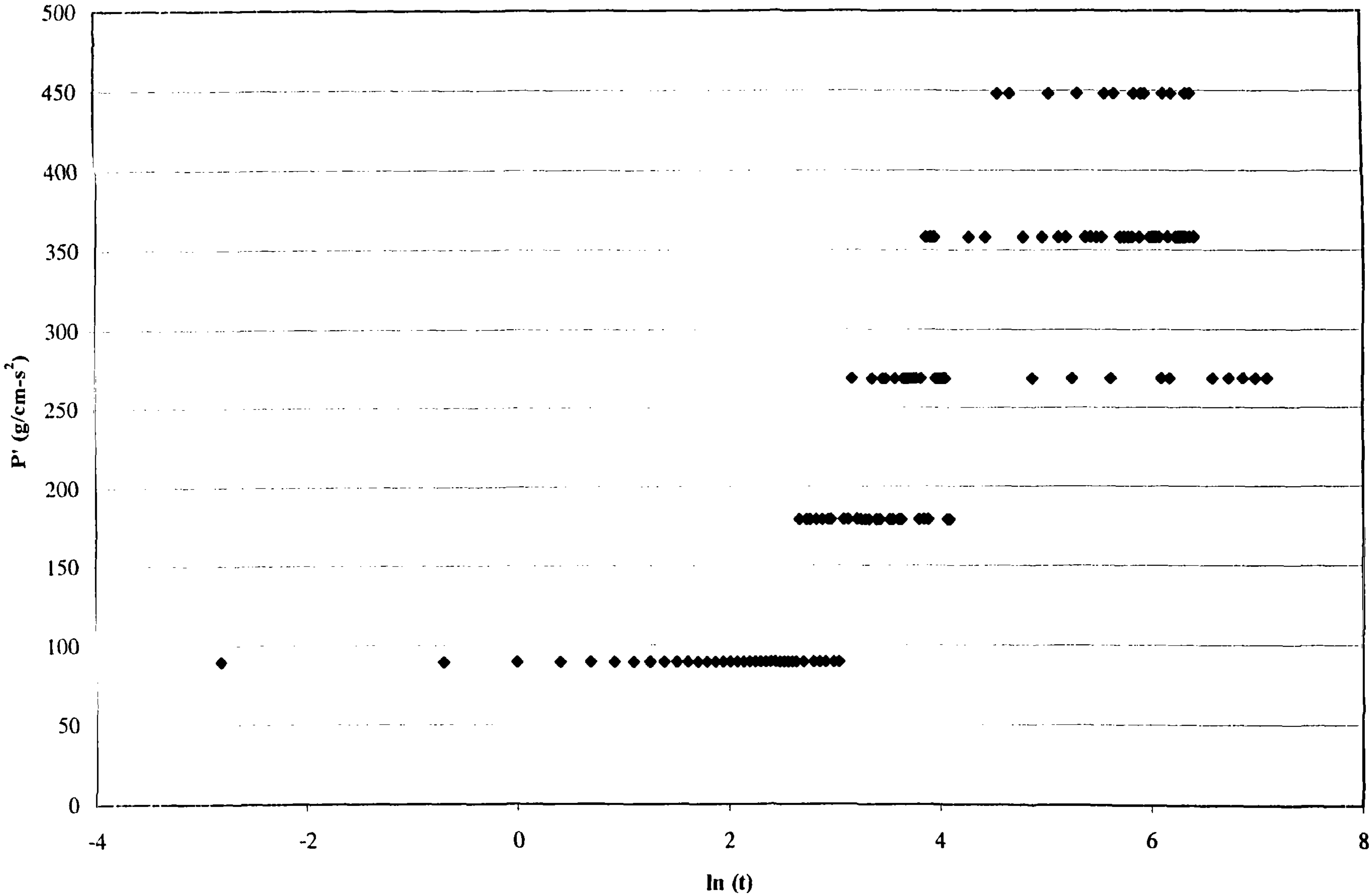
## Air Injection Permeability Tests
## Field Data
## VP-1



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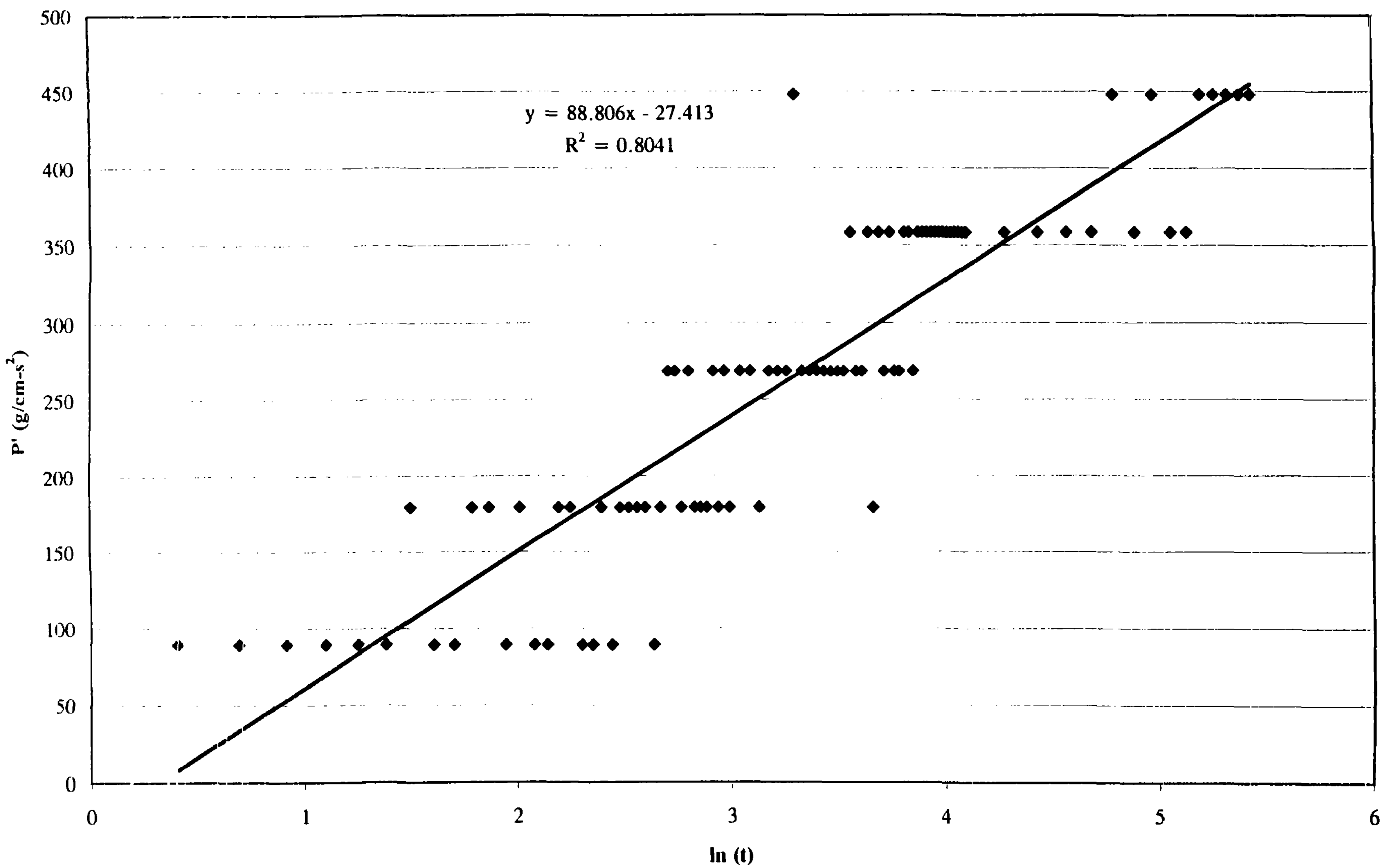
# Response Data
# Well VP-3



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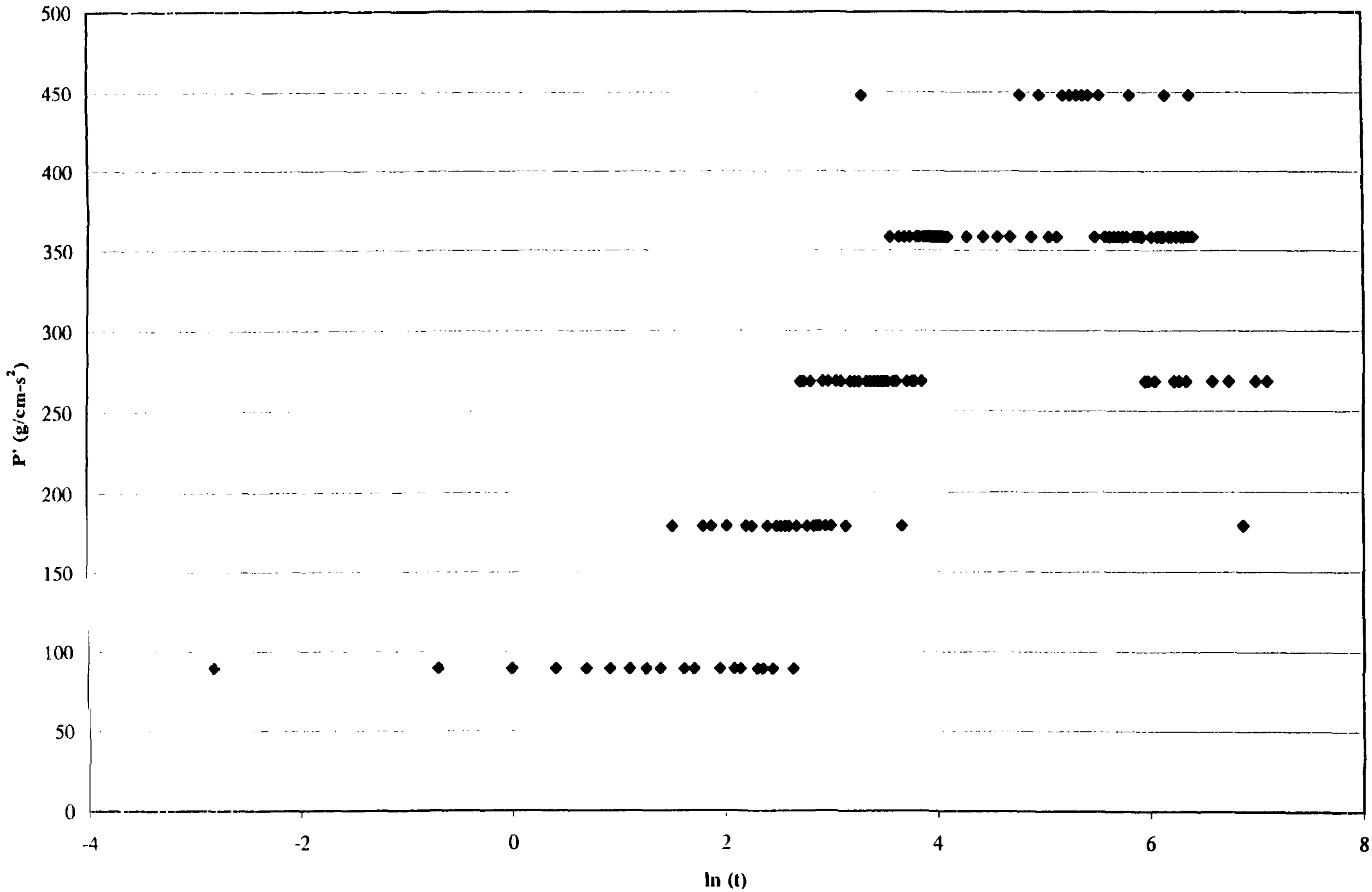
# Air Injection Permeability Tests
# Field Data
# Well VP-3



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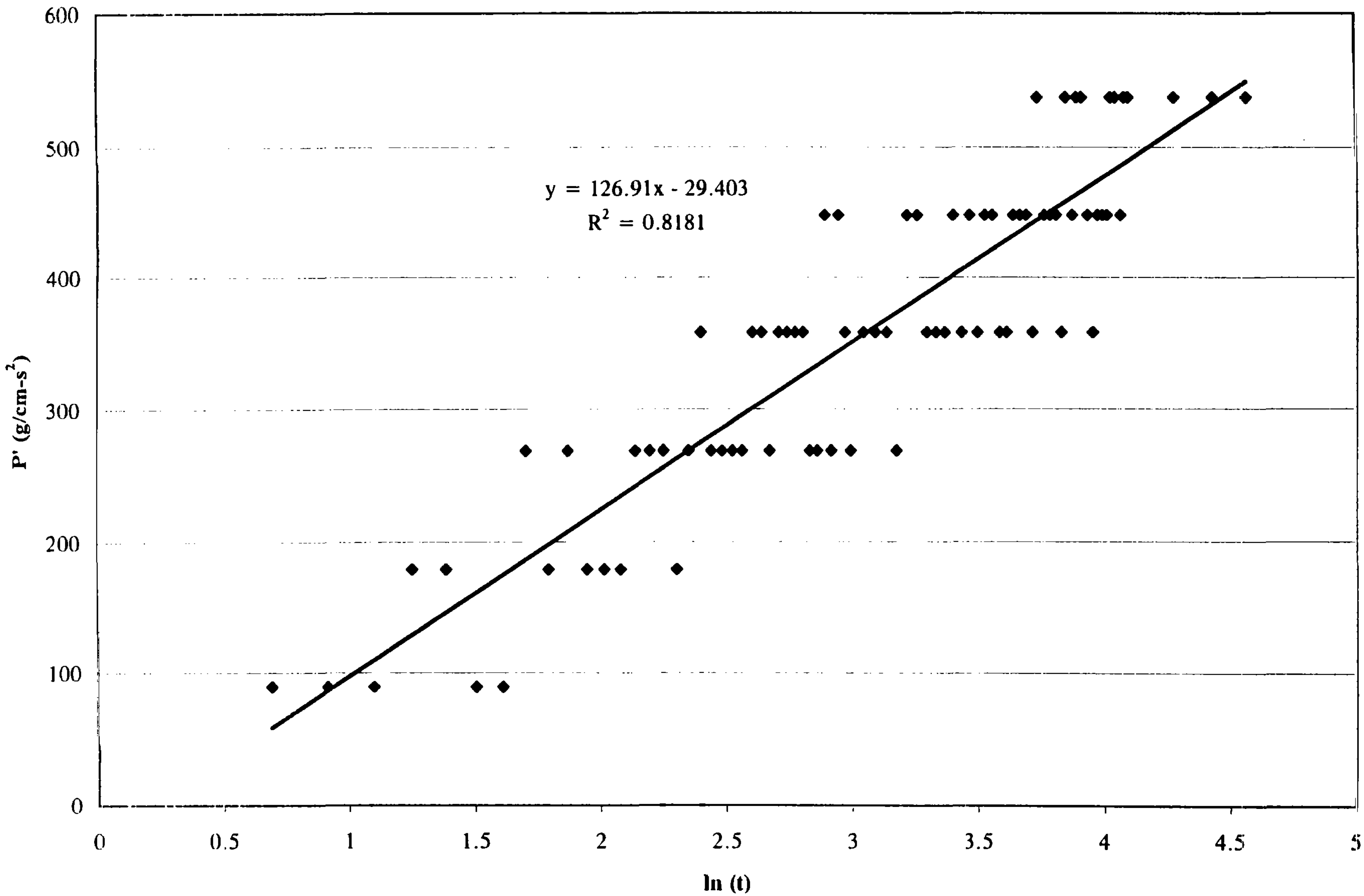
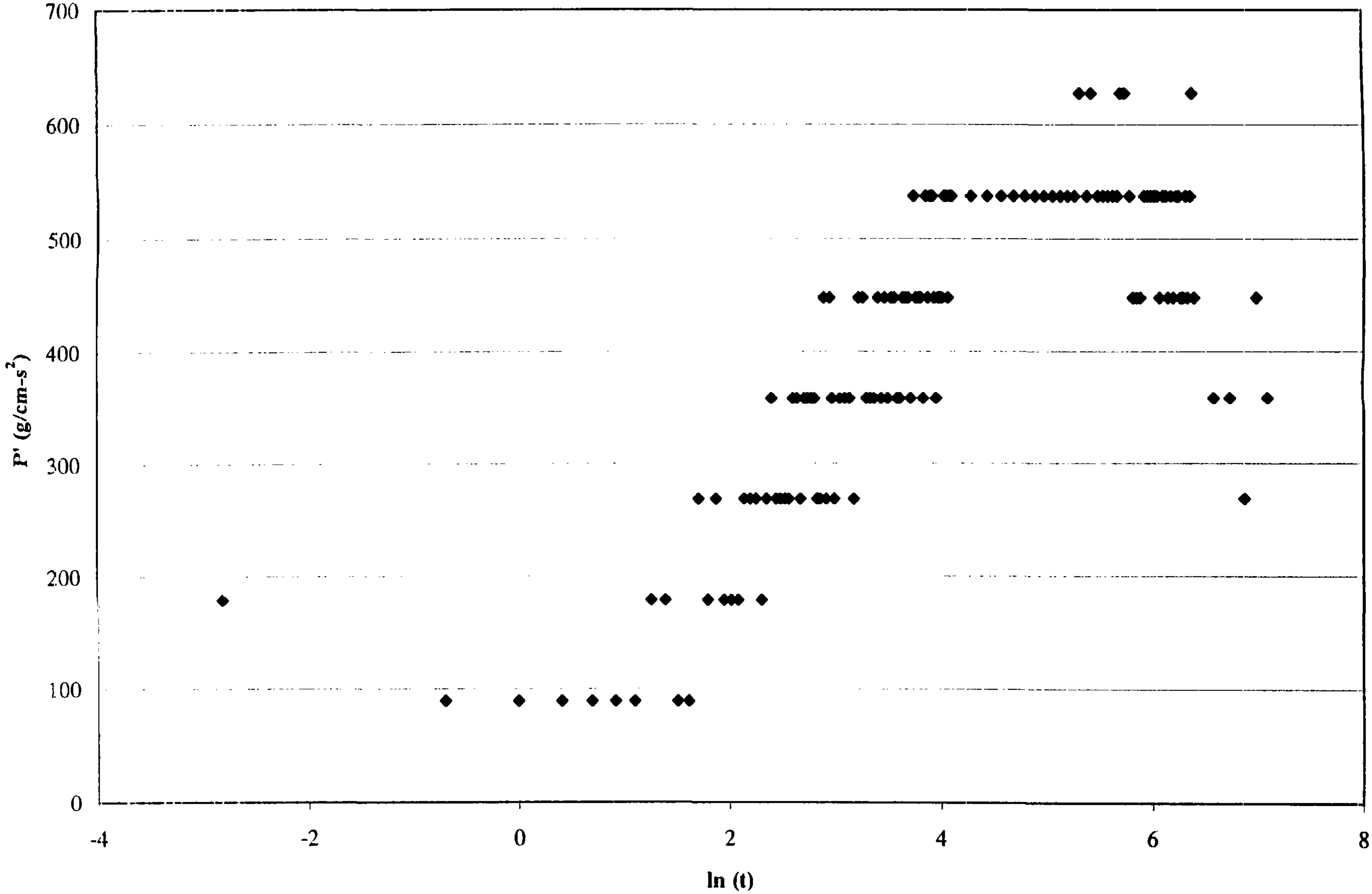
# Air Injection Permeability Tests
# Response Data
# Well VP-7



**Granville Solvents**
**Air Injection Permeability Tests**
**Field Data**
**Well VP-7**



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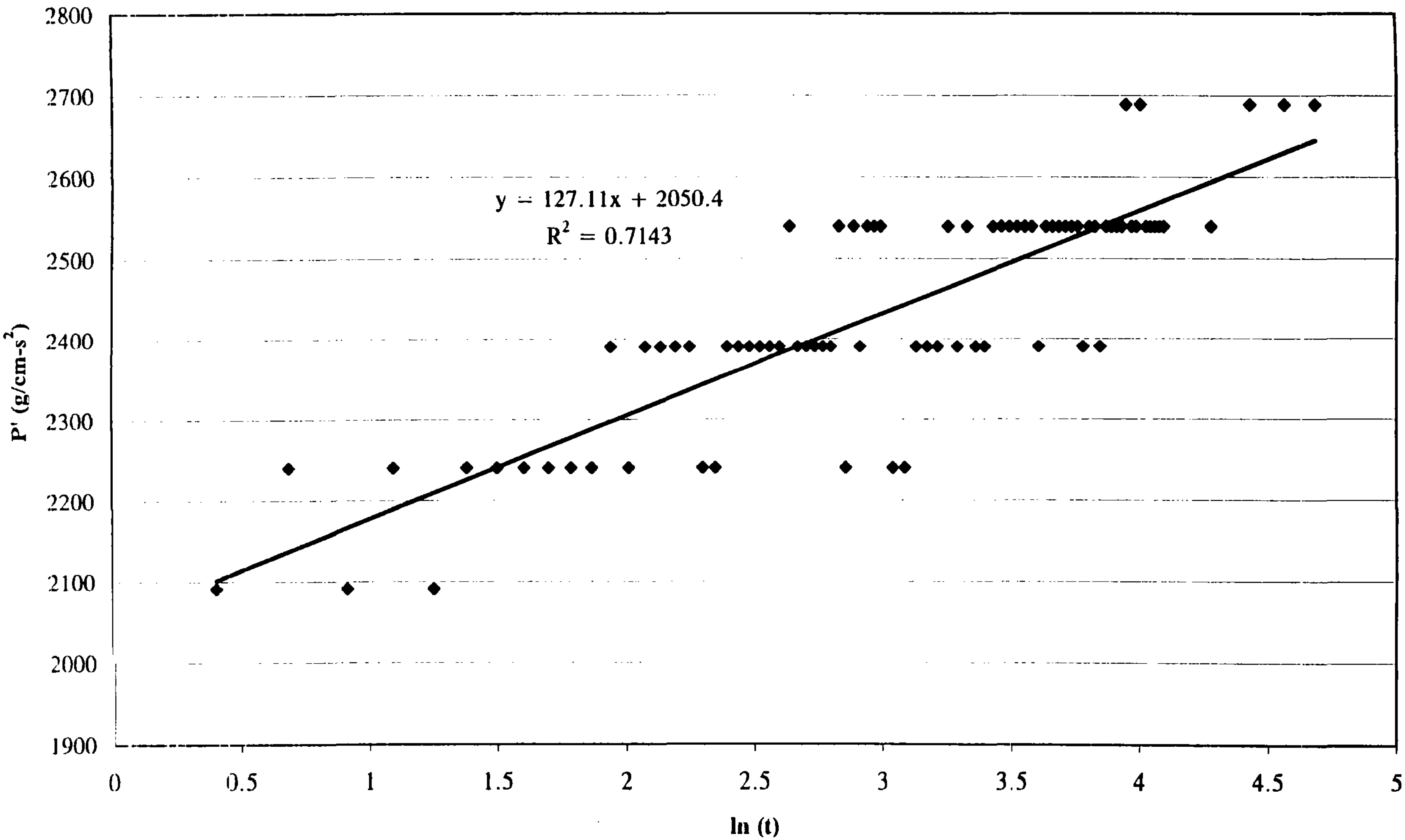
# Air Injection Permeability Tests
# Response Data
# Well VP-13



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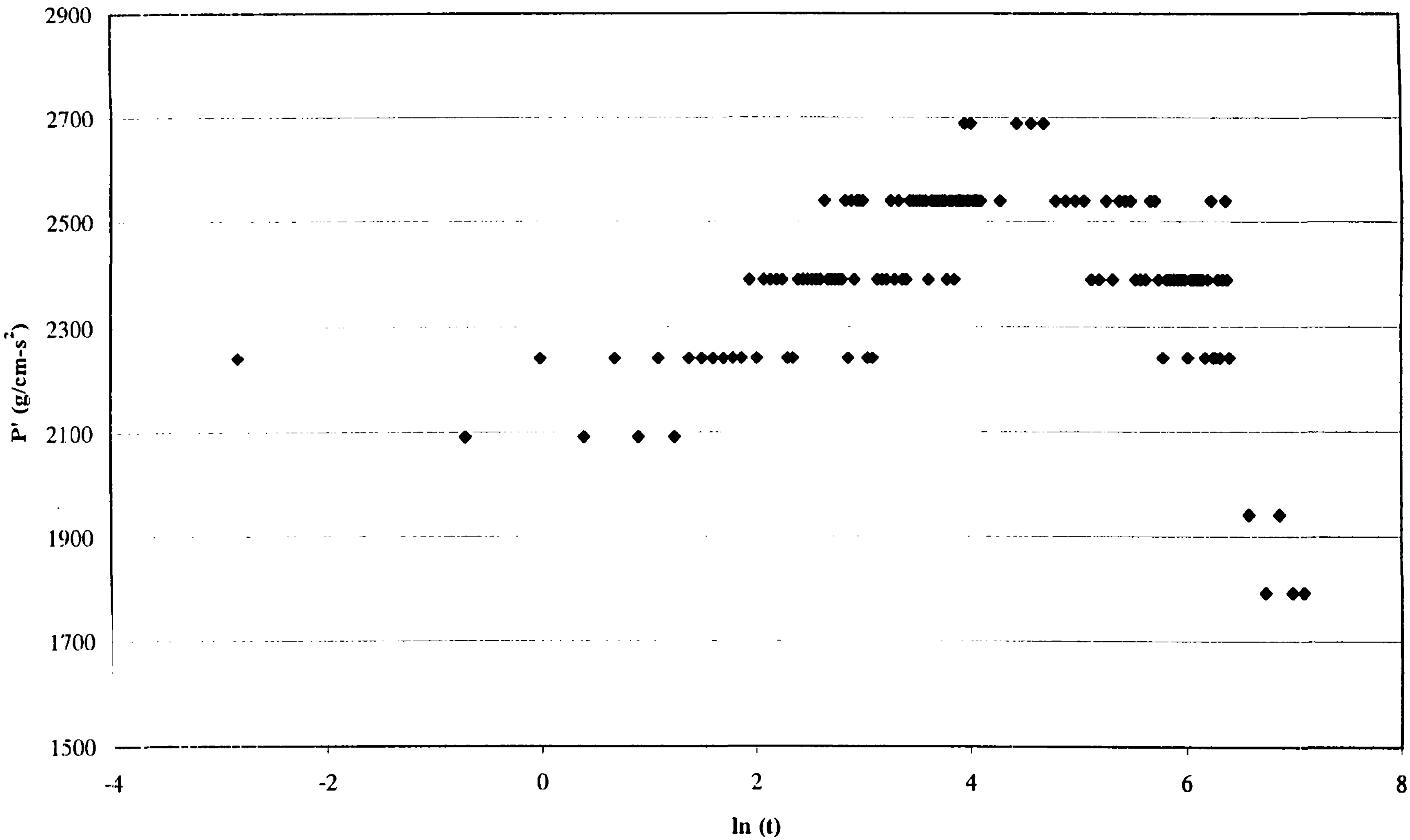
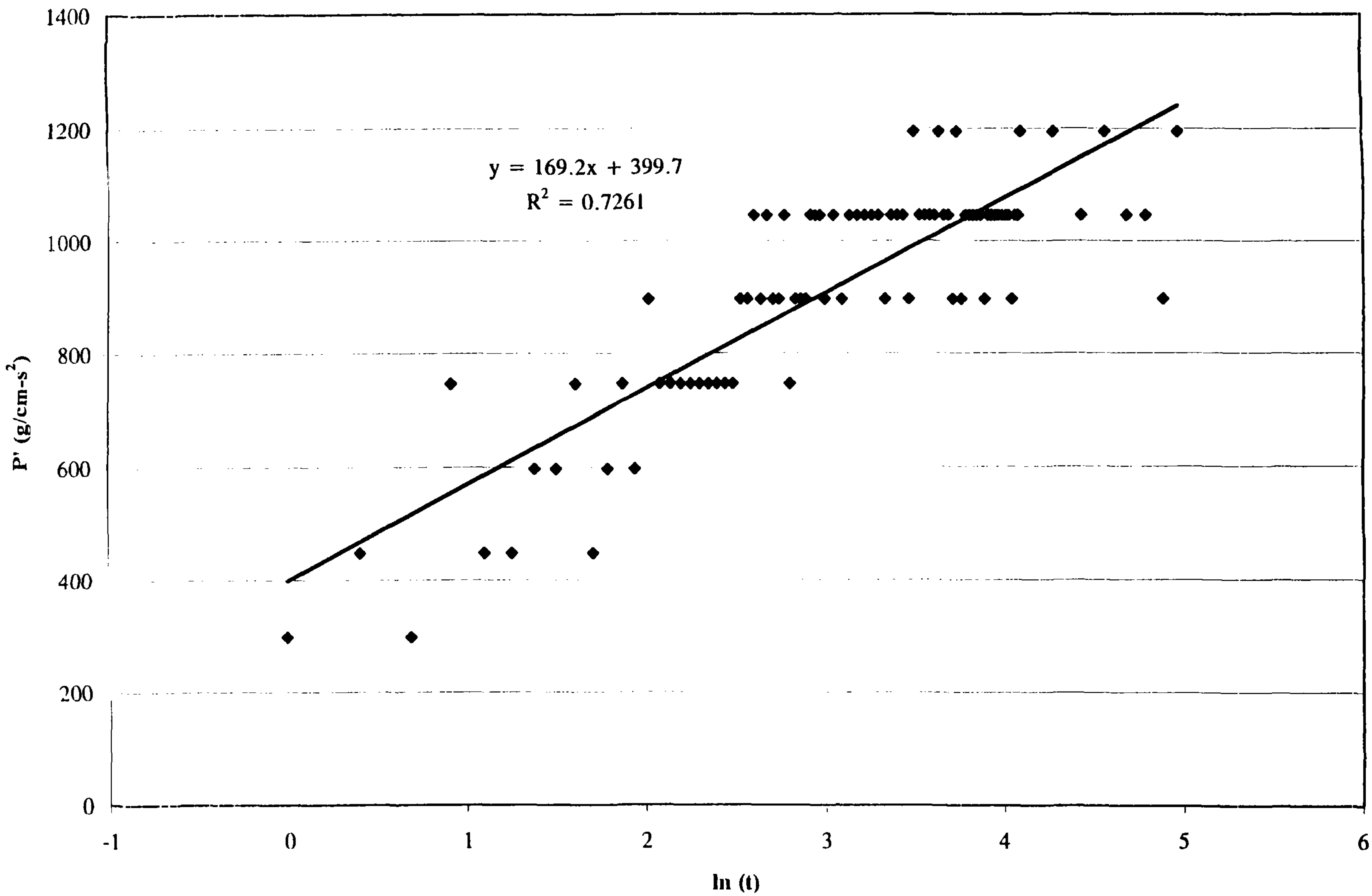
# Field Data
# Well VP-13



Granville Solvents
Air Injection Permeability Tests
Response Data
Well MW-P1



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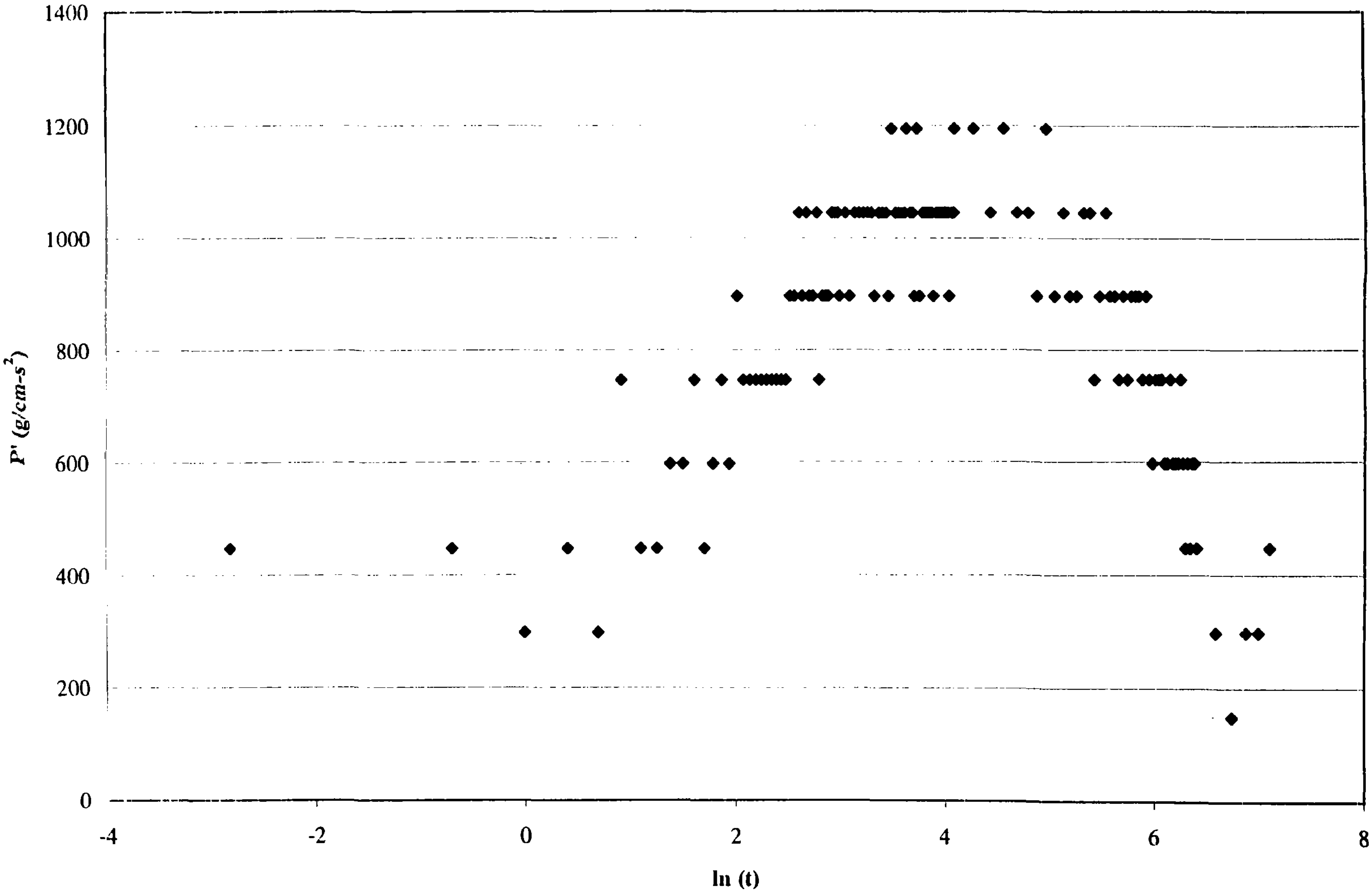
# Ait Injection Permeability Tests
# Field Data
# Well MW-P1



# APPENDIX B-2

# STEADY STATE CALCULATIONS

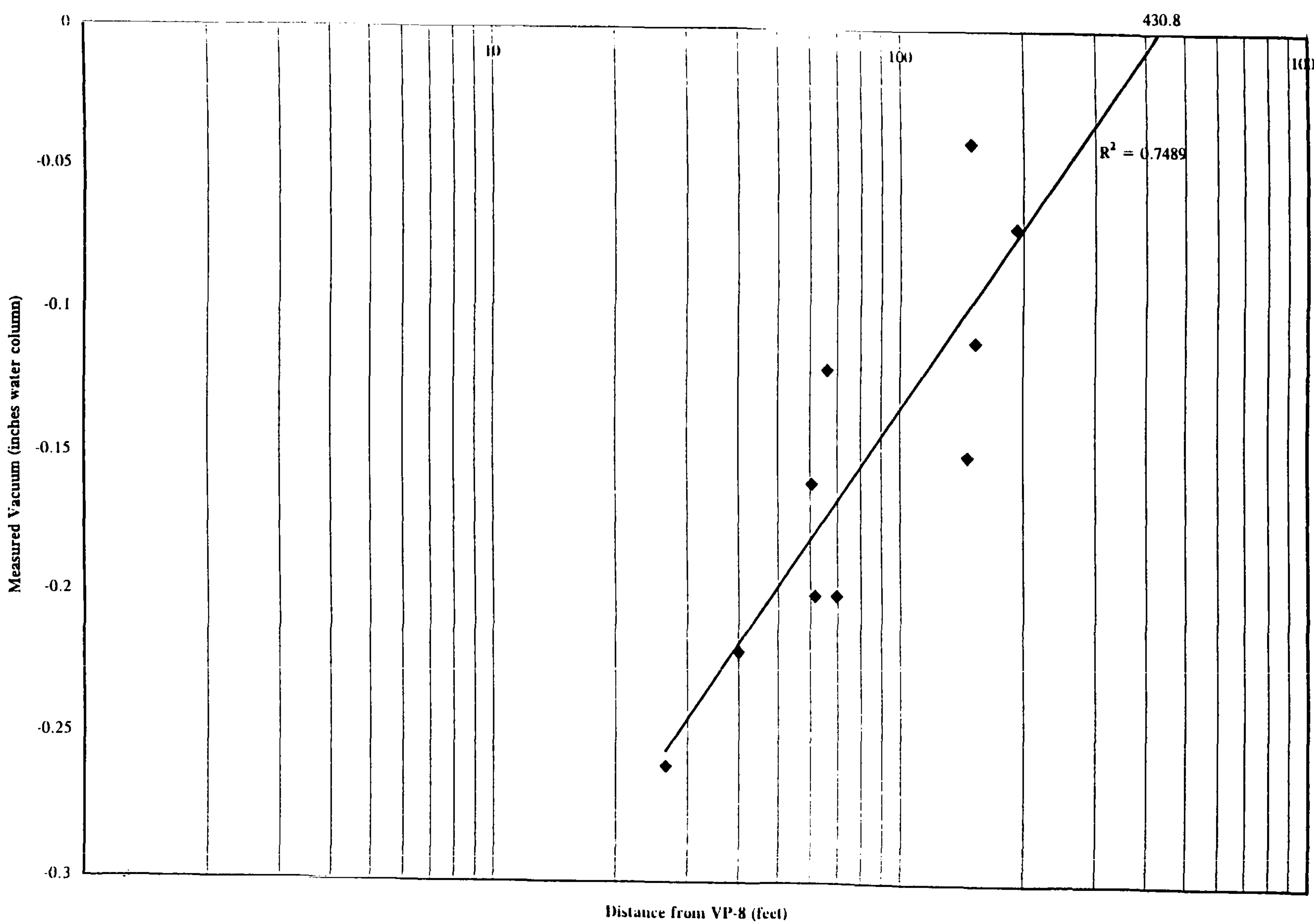
# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS

| Well | n or b (ft) | $P_{atm}$ (psi) | $Q_v$ (scfm) | Patm-P* (in.$H_2O$) | Patm-P (in.$H_2O$) | r (ft) | $r_e$ (ft) | $u$ (kg/msec) | Air temp. oF |
|---|---|---|---|---|---|---|---|---|---|
| VP-7 | 10 | 14.5 | 106.4 | 8.5 | 0.22 | 40 | 430.8 | 1.774E-05 | 50 |
| VP-9 | 10 | 14.5 | 106.4 | 8.5 | 0.2 | 43.5 | 430.8 | 1.774E-05 | 50 |
| VP-10 | 10 | 14.5 | 106.4 | 8.5 | 0.19 | 51.5 | 430.8 | 1.774E-05 | 50 |
| VP-1 | 10 | 14.5 | 106.4 | 8.5 | 0.2 | 61.5 | 430.8 | 1.774E-05 | 50 |
| VP-3 | 10 | 14.5 | 106.4 | 8.5 | 0.2 | 69.5 | 430.8 | 1.774E-05 | 50 |
| VP-11 | 10 | 14.5 | 106.4 | 8.5 | 0.44 | 55 | 430.8 | 1.774E-05 | 50 |
| PF2 | 10 | 14.5 | 106.4 | 8.5 | 0.02 | 53 | 430.8 | 1.774E-05 | 50 |
| PF1 | 10 | 14.5 | 106.4 | 8.5 | 0.55 | 44 | 430.8 | 1.774E-05 | 50 |
| VP-12 | 10 | 14.5 | 106.4 | 8.5 | 0 | 57.5 | 430.8 | 1.774E-05 | 50 |
| VP-4 | 10 | 14.5 | 106.4 | 8.5 | 0.16 | 60.5 | 430.8 | 1.774E-05 | 50 |
| VP-2 | 10 | 14.5 | 106.4 | 8.5 | 0.12 | 66 | 430.8 | 1.774E-05 | 50 |
| MW-P1 | 10 | 14.5 | 106.4 | 8.5 | 0.26 | 26.5 | 430.8 | 1.774E-05 | 50 |
| MW-1 | 10 | 14.5 | 106.4 | 8.5 | 0.11 | 153 | 430.8 | 1.774E-05 | 50 |
| MW-3 | 10 | 14.5 | 106.4 | 8.5 | 0.15 | 146.5 | 430.8 | 1.774E-05 | 50 |
| MW-2 | 10 | 14.5 | 106.4 | 8.5 | 0.04 | 149 | 430.8 | 1.774E-05 | 50 |
| MW-5 | 10 | 14.5 | 106.4 | 8.5 | 0.07 | 193 | 430.8 | 1.774E-05 | 50 |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# SUMMARY OF VALUES

| Well | P* (kg/msec$^2$) | P (kg/msec$^2$) | $k_a$ (m$^2$) | $k_a$ (darcies) | $K_a$ (cm/sec) | $K_w$ (cm/sec) | $K_w$ (ft/day) |
|---|---|---|---|---|---|---|---|
| VP-7 | 97873.825 | 99935.489 | 1.97602E-09 | 2001.4227 | 1.11E+02 | 1.69E+00 | 4.78E+03 |
| VP-1 | 97873.825 | 99940.469 | 1.78019E-09 | 1803.0708 | 99.83603 | 1.52E+00 | 4.31E+03 |
| VP-3 | 97873.825 | 99940.469 | 1.66835E-09 | 1689.7984 | 93.564139 | 1.42E+00 | 4.04E+03 |
| VP-4 | 97873.825 | 99950.429 | 2.24387E-09 | 2272.7065 | 125.83976 | 1.92E+00 | 5.43E+03 |
| VP-2 | 97873.825 | 99960.389 | 2.85906E-09 | 2895.812 | 160.34111 | 2.44E+00 | 6.92E+03 |
| MW-P1 | 97873.825 | 99925.53 | 1.96177E-09 | 1986.9831 | 1.10E+02 | 1.67E+00 | 4.75E+03 |
| MW-1 | 97873.825 | 99962.879 | 1.72109E-09 | 1743.2111 | 96.521597 | 1.47E+00 | 4.16E+03 |
| MW-3 | 97873.825 | 99952.919 | 1.31513E-09 | 1332.0303 | 73.75452 | 1.12E+00 | 3.18E+03 |
| MW-2 | 97873.825 | 99980.308 | 4.85369E-09 | 4916.0792 | 272.20331 | 4.14E+00 | 1.17E+04 |
| MW-5 | 97873.825 | 99972.838 | 2.09768E-09 | 2124.6467 | 117.64169 | 1.79E+00 | 5.08E+03 |

**Granville Solvents**
**Fracture SVE Pilot Testing**
**Distance-Vacuum Plot**



# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**VP-7**

Assume: Steady state conditions (u < 0.01)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{\pi b} \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | |
|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 in Hg | = | 99990.27 | kg/m $sec^2$ |
| | P*diff = | 8.50 in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 50 | $u$ = | 1.77E-05 kg/m sec | | | |
| | b = | 10 feet | = | 3.048 | m |
| | $r_e$ = | 430.8 feet | = | 131.3078 | m |
| | r = | 40 feet | = | 12.192 | m |
| | P diff = | 0.22 in $H_2O$ | = | 54.77851 | kg/m $sec^2$ |
| Calculated: | P* = | 97873.83 kg/m $sec^2$ | | | |
| | P = | 99935.49 kg/m $sec^2$ | | | |
| | $k_a$ = | 1.98E-09 $m^2$ | = | 2001.423 | darcies |
| | $K_a$ = | 110.8188 cm/sec | | | |
| | $K_w$ = | 1.69E+00 cm/sec | = | 4781.508 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**VP-1**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{pi\ b} \cdot \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | P*diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | b = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | r = | 61.5 | feet | = | 18.7452 | m |
| | P diff = | 0.2 | in $H_2O$ | = | 49.79865 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 | kg/m $sec^2$ | | | |
| | P = | 99940.47 | kg/m $sec^2$ | | | |
| | $k_a$ = | 1.78E-09 | $m^2$ | = | 1803.071 | darcies |
| | $K_a$ = | 99.83603 | cm/sec | | | |
| | $K_w$ = | 1.52E+00 | cm/sec | = | 4307.634 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**VP3**

Assume: Steady state conditions (u < 0.01)
One dimensional flow

Equation

$$k_a = \frac{Q_v P^* u}{\pi b} \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | |
|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 scfm | = | 0.050211 | $m^3/sec$ |
| | $P_{atm}$ = | 29.54 in Hg | = | 99990.27 | $kg/m\ sec^2$ |
| | $P^*diff$ = | 8.50 in H20 | = | 2116.442 | $kg/m\ sec^2$ |
| at 46F | $u$ = | 1.77E-05 kg/m sec | | | |
| | b = | 10 feet | = | 3.048 | m |
| | $r_e$ = | 430.8 feet | = | 131.3078 | m |
| | r = | 69.5 feet | = | 21.1836 | m |
| | P diff = | 0.2 in $H_2O$ | = | 49.79865 | $kg/m\ sec^2$ |
| Calculated: | $P^*$ = | 97873.83 $kg/m\ sec^2$ | | | |
| | P = | 99940.47 $kg/m\ sec^2$ | | | |
| | $k_a$ = | 1.67E-09 $m^2$ | = | 1689.798 | darcies |
| | $K_a$ = | 93.56414 cm/sec | | | |
| | $K_w$ = | 1.42E+00 cm/sec | = | 4037.021 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**VP4**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:
$$k_a = \frac{Q_v P^* u}{pi\ b} \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | $P^*$diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | b = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | r = | 60.5 | feet | = | 18.4404 | m |
| | P diff = | 0.16 | in $H_2O$ | = | 39.83892 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 | kg/m $sec^2$ | | | |
| | P = | 99950.43 | kg/m $sec^2$ | | | |
| | $k_a$ = | 2.24E-09 | $m^2$ | = | 2272.707 | darcies |
| | $K_a$ = | 125.8398 | cm/sec | | | |
| | $K_w$ = | 1.92E+00 | cm/sec | = | 5429.62 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**VP2**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{pi\ b} \cdot \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | *radius of pressure influence* (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | |
|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 in Hg | = | 99990.27 | kg/m $sec^2$ |
| | P*diff = | 8.50 in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 kg/m sec | | | |
| | b = | 10 feet | = | 3.048 | m |
| | $r_e$ = | 430.8 *feet* | = | 131.3078 | *m* |
| | r = | 66 feet | = | 20.1168 | m |
| | P diff = | 0.12 in $H_2O$ | = | 29.87919 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 kg/m $sec^2$ | | | |
| | P = | 99960.39 kg/m $sec^2$ | | | |
| | $k_a$ = | 2.86E-09 $m^2$ | = | 2895.812 | darcies |
| | $K_a$ = | 160.3411 cm/sec | | | |
| | $K_w$ = | 2.44E+00 cm/sec | = | 6918.253 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**MW-P1**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:
$$k_a = \frac{Q_v P^* u}{pi\ b} \quad \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | |
|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 in Hg | = | 99990.27 | kg/m $sec^2$ |
| | $P^*$diff = | 8.50 in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 kg/m sec | | | |
| | b = | 10 feet | = | 3.048 | m |
| | $r_e$ = | 430.8 feet | = | 131.3078 | m |
| | r = | 26.5 feet | = | 8.0772 | m |
| | P diff = | 0.26 in $H_2O$ | = | 64.73824 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 kg/m $sec^2$ | | | |
| | P = | 99925.53 kg/m $sec^2$ | | | |
| | $k_a$ = | 1.96E-09 $m^2$ | = | 1986.983 | darcies |
| | $K_a$ = | 110.0193 cm/sec | | | |
| | $K_w$ = | 1.67E+00 cm/sec | = | 4747.011 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**MW-1**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{pi\ b} \quad \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| $b$ | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| $r$ | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | $P^*$diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | $b$ = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | $r$ = | 153 | feet | = | 46.6344 | m |
| | P diff = | 0.11 | in $H_2O$ | = | 27.38926 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 | kg/m $sec^2$ | | | |
| | $P$ = | 99962.88 | kg/m $sec^2$ | | | |
| | $k_a$ = | 1.72E-09 | $m^2$ | = | 1743.211 | darcies |
| | $K_a$ = | 96.5216 | cm/sec | | | |
| | $K_w$ = | 1.47E+00 | cm/sec | = | 4164.626 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**MW-3**

Assume: Steady state conditions ($u < 0.01$)
One dimensional flow

Equation: $$k_a = \frac{Q_v P^* u}{\text{pi } b} \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement, adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | $P^*$diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | b = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | r = | 146.5 | feet | = | 44.6532 | m |
| | P diff = | 0.15 | in $H_2O$ | = | 37.34898 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 | kg/m $sec^2$ | | | |
| | P = | 99952.92 | kg/m $sec^2$ | | | |
| | $k_a$ = | 1.32E-09 | $m^2$ | = | 1332.03 | darcies |
| | $K_a$ = | 73.75452 | cm/sec | | | |
| | $K_w$ = | 1.12E+00 | cm/sec | = | 3182.293 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**MW-2**

Assume: Steady state conditions (u < 0.01)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{\text{pi } b} \cdot \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement. adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | $P^*$diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | b = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | r = | 149 | feet | = | 45.4152 | m |
| | P diff = | 0.04 | in $H_2O$ | = | 9.959729 | kg/m $sec^2$ |
| Calculated: | $P^*$ = | 97873.83 | kg/m $sec^2$ | | | |
| | P = | 99980.31 | kg/m $sec^2$ | | | |
| | $k_a$ = | 4.85E-09 | $m^2$ | = | 4916.079 | darcies |
| | $K_a$ = | 272.2033 | cm/sec | | | |
| | $K_w$ = | 4.14E+00 | cm/sec | = | 11744.78 | ft/day |

# GRANVILLE SOLVENTS PILOT TESTING
# STEADY STATE SOIL PERMEABILITY CALCULATIONS
# EFFECTIVE RADIUS METHOD

Steady State Solution for One Dimensional Radial Flow
Soil Vapor Extraction Pilot Testing
Theoretical basis for these calculations is provided in USACE Soil Vapor Extraction and Bioventing Manual, Chapter 2

**MW-5**

Assume: Steady state conditions (u < 0.01)
One dimensional flow

Equation:

$$k_a = \frac{Q_v P^* u}{pi\ b} \frac{\ln(r_e/r)}{P^2 - P_{atm}^2}$$

where:

| | | |
|---|---|---|
| $Q_v$ | = | volumetric flow rate (L^3/T) |
| $P^*$ | = | absolute pressure at the point of flow measurement. adjusted for well loss (M/LT^2) |
| $P$ | = | absolute pressure at the observation well. (M/LT^2) |
| $P_{atm}$ | = | atmosphere pressure (absolute) during test (M/LT^2) |
| $u$ | = | dynamic viscosity of soil gas (M/LT) |
| pi | = | 3.1415926 |
| b | = | Aquifer thickness (L) |
| $r_e$ | = | radius of pressure influence (L) |
| r | = | Distance from VE1 to observation well (L) |
| $k_a$ | = | apparent air permeability (L^2) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Input: | $Q_v$ = | 106.40 | scfm | = | 0.050211 | $m^3$/sec |
| | $P_{atm}$ = | 29.54 | in Hg | = | 99990.27 | kg/m $sec^2$ |
| | P*diff = | 8.50 | in H20 | = | 2116.442 | kg/m $sec^2$ |
| at 46F | $u$ = | 1.77E-05 | kg/m sec | | | |
| | b = | 10 | feet | = | 3.048 | m |
| | $r_e$ = | 430.8 | feet | = | 131.3078 | m |
| | r = | 193 | feet | = | 58.8264 | m |
| | P diff = | 0.07 | in $H_2O$ | = | 17.42953 | kg/m $sec^2$ |
| Calculated: | P* = | 97873.83 | kg/m $sec^2$ | | | |
| | P = | 99972.84 | kg/m $sec^2$ | | | |
| | $k_a$ = | 2.1E-09 | $m^2$ | = | 2124.647 | darcies |
| | $K_a$ = | 117.6417 | cm/sec | | | |
| | $K_w$ = | 1.79E+00 | cm/sec | = | 5075.897 | ft/day |

# APPENDIX B-3

# BORING LOGS FOR
# SB-14/VP-14 and SB-15/VP15

Metcalf & Eddy

# GEOLOGIC LOG

| | | | |
|---|---|---|---|
| PROJECT: Granville Solvents | | SHEET 1 OF 2 | BORING NO.: SB-14 |
| SITE LOCATION: Granville, Ohio | JOB NO.: 025508-2000-200 | | |
| | LOCATION: Southwest corner of Warehouse Building | GROUND ELEVATION: 917.66 | TOTAL DEPTH: 18 ft / START: 6-15-00 END: 6-15-00 |
| DRILLING COMPANY: Wright's Drilling | | DRILLING RIG: CME 75 | |
| DRILLER(s): Darrell Wright | | METHOD: Hollow Stem Auger | |
| GEOLOGIST: Mark Andrew | | AUGER SIZE: 4 ½ inches | |
| WATER ZONE ENCOUNTERED: | | STATIC WATER LEVEL: 16 FEET | |

| TIME | SAMPLE TYPE\ NO | SAMPLE DEPTH | SAMPLE RECOVERY | BLOW COUNT | % RECOVERY | SAMPLE DESCRIPTION | DRILLING NOTES (Hnu) |
|---|---|---|---|---|---|---|---|
| 10:44 | SS | 0-2 | 1.5 | 3, 6 11, 18 | 75 | Topsoil profile with cinders 0-6", 6"-2.0' Silty Clay (CL), weathered till, 10YR4/3 trace gravel, 10% sand, 20% silt, firm, dense, moist. | |
| 10:48 | SS | 2-4 | 2.0 | 8, 11, 16, 11 | 100 | Silty Clay (CL) as above. | |
| 10:52 | SS | 4-6 | 1.0 | 5, 4, 4, 7 | 55 | Silty Clay (CL), loose almost friable, 20% gravel, 20% sand, 20% silt, moist to wet,. | |
| 8:59 | SS | 6-8 | 1.5 | 6, 9, 11, 12 | 75 | Same Clay 6-6.5ft. 6.5-8 ft Sand (SM), 20 % small gravel, 10% silt, poorly sorted, subrounded, bank run, large cobble at 8 ft., drilled past. As above, poorly sorted, bank run, sand (SM). | |
| 9:05 | SS | 8-10 | 2.0 | 15, 16, 17, 18 | 100 | Sand (SM) As above, 20% gravel, 10% silt, subrounded, bank run. | |
| 9:11 | SS | 10-12 | 2.0 | 10, 12, 16, 21 | 100 | As above poorly sorted sand. | |
| 9:22 | SS | 12-14 | 2.0 | 12, 14, 28, 40 | 100 | Same as above material. | |
| 9:32 | SS | 14-16 | 2.0 | 44, 38, 24, 28 | 100 | | |
| 9:38 | SS | 16-17 | 2.0 | 36, 22, 36, 34 | 100 | Same as above material. | |

# GEOLOGIC LOG

Metcalf & Eddy

| PROJECT: Granville Solvents | JOB NO.: 025508-2000-200 | SHEET 2 OF 2 | BORING NO.: SB-14 |
|---|---|---|---|
| LOCATION: Midpoint of Building Southside | | | |

| TIME | SAMPLE NO.\ TYPE | SAMPLE DEPTH | SAMPLE RECOVERY | BLOW COUNT | % RECOVERY | SAMPLE DESCRIPTION | DRILLING NOTES (Hnu) |
|---|---|---|---|---|---|---|---|
| 9:48 | SS | 17-19 | 2.0 | 16, 21, 16, 20 | 100 | Same as above material. Saturated at 18.5 ft. | |
| | | | | | | SCREEN: 7 - 17 FEET<br>SAND: 6 - 17 FEET<br>BENTONITE CHIPS: 0-6 FEET | |
| | | | | | | END OF BORING AT 20 FEET | |

# GEOLOGIC LOG

Metcalf & Eddy

| | | | |
|---|---|---|---|
| PROJECT: **Granville Solvents** | | SHEET 1 OF 2 | BORING NO.: **SB-MW-15** |
| SITE LOCATION: **Granville, Ohio** | JOB NO.: **025508-2000-200** | | |
| | LOCATION: **Midpoint of Building Southside** | GROUND ELEVATION: 917.14 | TOTAL DEPTH: **18 ft** / START: **6-15-00** END: **6-15-00** |
| DRILLING COMPANY: **Wright's Drilling** | | DRILLING RIG: **CME 75** | |
| DRILLER(s): **Darrell Wright** | | METHOD: **Hollow Stem Auger** | |
| GEOLOGIST: **Mark Andrew** | | AUGER SIZE: **4 ¼ inches** | |
| WATER ZONE ENCOUNTERED: | | STATIC WATER LEVEL: **18 FEET** | |

| TIME | SAMPLE TYPE\ NO. | SAMPLE DEPTH | SAMPLE RECOVERY | BLOW COUNT | % RECOVERY | SAMPLE DESCRIPTION | DRILLING NOTES (Hnu) |
|---|---|---|---|---|---|---|---|
| 10:44 | SS | 0-2 | 1.5 | 3, 6, 11, 18 | 75 | Topsoil profile with cinders 0-6", 6"-2.0' Silty Clay (CL), weathered till, 10YR4/3 trace gravel, 10% sand, 20% silt, firm, dense, moist. | 1.5 |
| 10:48 | SS | 2-4 | 2.0 | 8, 11, 16, 11 | 100 | Silty Clay (CL) as above. | 3.5 |
| 10:52 | SS | 4-6 | 1.0 | 5, 4, 4, 7 | 55 | Silty Clay (CL), loose almost friable, 20% gravel, 20% sand, 20% silt, moist to wet, almost looks like fill but material at 0-4 ft insitu. | |
| 10:57 | SS | 6-8 | 2.0 | 10, 11, 8, 17 | 100 | 6-7 ft as above material.<br>7-8 ft Sand (SM) with 20% gravel, 10% silt, poorly sorted, bank run. | |
| 11:05 | SS | 8-10 | 0.75 | 10, 13, 27, 30 | 35 | As above Sand, drove cobble. | |
| 11:10 | SS | 10-12 | 2.0 | 20, 22, 26, 31 | 100 | As above poorly sorted bank run sand. | |
| 11:17 | SS | 12-14 | 0.6 | 21 50/5" | | Same as above material, cobble at 12.5 ft, large cobble stopped augers. | |
| 11:29 | SS | 14-16 | 2.0 | 49, 37, 27, 15 | 100 | Sand and Gravel (SM/CM), 10% cobbles, 10% silt, 40% sand and gravel, poorly sorted, very moist at base. | |

Metcalf & Eddy

# GEOLOGIC LOG

| PROJECT: Granville Solvents | JOB NO.: 025508-2000-200 | SHEET 2 OF 2 | BORING NO.: SB-MW-15 |
|---|---|---|---|
| LOCATION: | | | |

| TIME | SAMPLE NO.\ TYPE | SAMPLE DEPTH | SAMPLE RECOVERY | BLOW COUNT | % RECOVERY | SAMPLE DESCRIPTION | DRILLING NOTES (Hnu) |
|---|---|---|---|---|---|---|---|
| 11:38 | SS | 16-18 | 2.0 | 21, 21, 21, 18 | 100 | Same as above material, drill out to 18 feet. | |
| | | | | | | SCREEN: 8-18 FEET<br>SAND: 7-18 FEET<br>BENTONITE CHIPS: 0-7 FEET | |
| | | | | | | END OF BORING AT 18 FEET | |